CHARACTERIZATION OF RESIDUAL FEED INTAKE AND RELATIONSHIPS WITH PERFORMANCE, CARCASS AND TEMPERAMENT TRAITS IN GROWING CALVES

A Thesis

by

JAMES TRENT FOX

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2004

Major Subject: Animal Science

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ABSTRACT

Characterization of Residual Feed Intake and Relationships with Performance, Carcass and Temperament Traits in Growing Calves. (August 2004)

James Trent Fox, B.S., Kansas State University

Chair of Advisory Committee: Dr. Gordon Carstens

The objectives of this study were accomplished with two experiments in growing Bonsmara bulls (N = 68) (experiment 1), and Simmental crossbred calves (N = 132) (experiment 2). Specific objectives for experiment 1 were to characterize residual feed intake (RFI) in growing bulls, and examine relationships between RFI and performance, fertility, temperament and body composition traits. In experiment 2, the objectives were to examine stocker-phase supplementation effects on feedlot feed conversion ratio (FCR) and RFI and to characterize relationships between these feed efficiency traits, and performance and carcass traits in finishing calves. In both experiments, individual feed intakes and BW were measured. Ultrasound technology was used to measure body composition in experiment 1, while actual carcass measurements taken at harvest were used for experiment 2. Experiment 1 demonstrated that temperament affected ADG and DMI, but not FCR or RFI. Residual feed intake was not phenotypically correlated to scrotal circumference or bull fertility traits. Experiments 1 and 2 demonstrated that RFI was independent of ADG and BW, but that there was a tendency ($P < 0.10$) for RFI to be phenotypically correlated with 12th rib fat thickness ($r = 0.20$ and 0.22). However, RFI was not correlated with longissimus muscle area in either experiment. Both experiments demonstrated that low RFI (< 0.5 SD below mean RFI) calves consumed significantly

(20 and 22%) less feed and had improved (21%) FCR compared to calves with high RFI (> 0.5 SD above mean RFI). Results from experiment 2 suggest that RFI measured while calves are consuming high-grain diets may be less influenced by previous level of stocker supplementation compared to FCR or residual gain efficiency traits. In summary, RFI was found to be phenotypically independent of growth rate and BW, had no effect on bull fertility or temperament traits, and was less impacted by previous plane of nutrition compared to FCR.

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INTRODUCTION

For many years, beef cattle have been selected primarily on growth traits such as yearling weight, feedlot average daily gain (ADG), and mature weight. As the industry has evolved and new technology has been implemented, the process of selecting breeding stock has become more complicated. The wide spread use of expected progeny differences (EPD) by the seedstock industry has lead to significant improvements in growth traits such as weaning and yearling BW, and postweaning ADG (Mahrt et al., 1990). More recently, the industry has focused on carcass composition and quality traits. Evidence of improvements in quality grade achieved by employing ultrasound technology as a selection tool can be seen in Sapp et al. (2002). Use of this technology will benefit beef producers that retain ownership as these cattle will generate more income based on carcass grid formulas.

The primary limitation to current selection programs is that the input costs are not considered. If breeding animals were selected based on feed efficiency, input costs could be reduced. Feed is the single largest variable cost of beef production in most commercial operations (Arthur et al., 1996). The poultry and swine industries have shown significantly lower cost of production by selecting for more efficient animals (Arthur et al., 1997). An improved level of efficiency could save cattle feeders millions of dollars a year in feed costs making beef production more profitable for confined feeding situations as well as reducing feed requirements of breeding stock.

This thesis follows the style and format of Journal of Animal Science.

REVIEW OF LITERATURE

Measures of Feed Efficiency

Feed Conversion Ratio. Feed efficiency has traditionally been measured as feed conversion ratio (FCR) which is daily feed intake divided by daily body weight gain. FCR is a gross measure of feed efficiency that does not attempt to account for animal differences in requirements for maintenance and growth (Arthur et al., 1996; Mrode et al., 1990; Bishop et al., 1991). Montaño-Bermudez et al. (1990) demonstrated that feed needed to support maintenance requirements represents approximately 60 to 65% of the total feed requirement of the cow herd. Arthur et al. (1996) suggested that measurements of feed efficiency should incorporate or take into account animal variation in energy requirement for maintenance and growth. The Beef Improvement Federation (2002) outlines methods to adjust FCR for maintenance requirements based on metabolic weight ($BW^{0.75}$) of the animal. Another limitation to FCR as a measure of feed efficiency is that FCR is negatively correlated genetically with ADG (Koots et al., 1994b). Gunsett (1984) concluded that a linear index of a two-component trait improves selection response when compared to direct selection of a two-component trait expressed as a ratio.

Residual Feed Intake. A new method of measuring feed efficiency was originally proposed by Koch et al. (1963) which uses a statistical model to adjust feed consumption for differences in gain (residual feed intake) or adjust gain for differences in feed consumption (residual gain). Basarab et al. (2001) states that RFI may be related to the requirements needed to maintain the animal independent of growth, size or appetite. Residual feed intake is an alternative measure of feed efficiency that is genetically independent of level of production and body size (Arthur et al., 2001a). Growth is used as the measure of production in growing/finishing cattle, where as milk production is used as the measure of production in lactating dairy cows. Residual feed intake is expressed as the difference between actual feed intake and expected feed intake. More efficient cattle will eat less than expected for their body size and level of production and have negative RFI values. There are two methods used to determine expected feed intake, the first method uses NRC equations to predict feed intake dependent upon weight of the animal, weight gain of the animal, and energy content of the diet. A drawback to this method can be seen in Liu et al. (2000) in which NRC equations predicted on average, higher intakes than was actually consumed by the animals meaning this particular group of bulls was at a higher level of energy utilization efficiency than NRC standards. In this study, RFI calculated using NRC equations was phenotypically correlated ($r = -0.55$; $P < 0.01$) with ADG. Research has shown that RFI calculated using net energy equations is not genetically independent of ADG and BW (Fan et al., 1995). The second method of calculating RFI, involves the use of linear regression models. In this method, expected intake is determined using a linear regression model of feed intake on metabolic body size and level of production within a contemporary group of animals (Arthur et al., 1996). If the linear regression method is used, genetic improvement of feed efficiency can be made through selection for low RFI without profound effects on ADG or other postweaning traits (Arthur et al., 2001a).

Residual feed intake is measured by feeding animals and recording individual feed intakes over a period of at least 70 d while simultaneously recording body weight gain. The benefits of selecting for RFI were demonstrated in a study by Arthur et al. (1996) which found that the most efficient animals consumed, on average, 13.5% less feed than predicted, and that the least efficient animals consumed, on average, 14% more feed than expected. In a study which measured RFI in bulls for 140 days, Liu et al. (2000) reported that the feed cost for the least efficient bull was $58.33 more compared to the most efficient bull even though the bulls weighed and gained the same. Archer et al. (2002) found that RFI of growing heifers was highly correlated to RFI of mature cows fed a similar diet, suggesting that applying selection pressure against RFI in growing calves will improve efficiency of the breeding herd without altering cow mature size. In contrast, if growing calves were selected for improved FCR it is likely that cow size would increase with nominal effects on feed intake. Koots et al. (1994b) reported a phenotypic correlation between FCR and mature size of -0.15 meaning as animals decreased in FCR their mature BW increased. Although FCR and RFI differ in affects on growth and mature size, they are still positively correlated (Figure 1, Table 1). Genetic correlations reported by Arthur et al. (2001a) between feed intake, and RFI and FCR were 0.69 and 0.31, respectively.

One limitation to applying selection pressure against RFI is the fact that measuring feed intake in cattle is expensive. Archer et al. (1999) stated that the best way to improve efficiency of beef production would be to improve feed utilization of breeding cows, but the feasibility of measuring intake on mature animals is low.

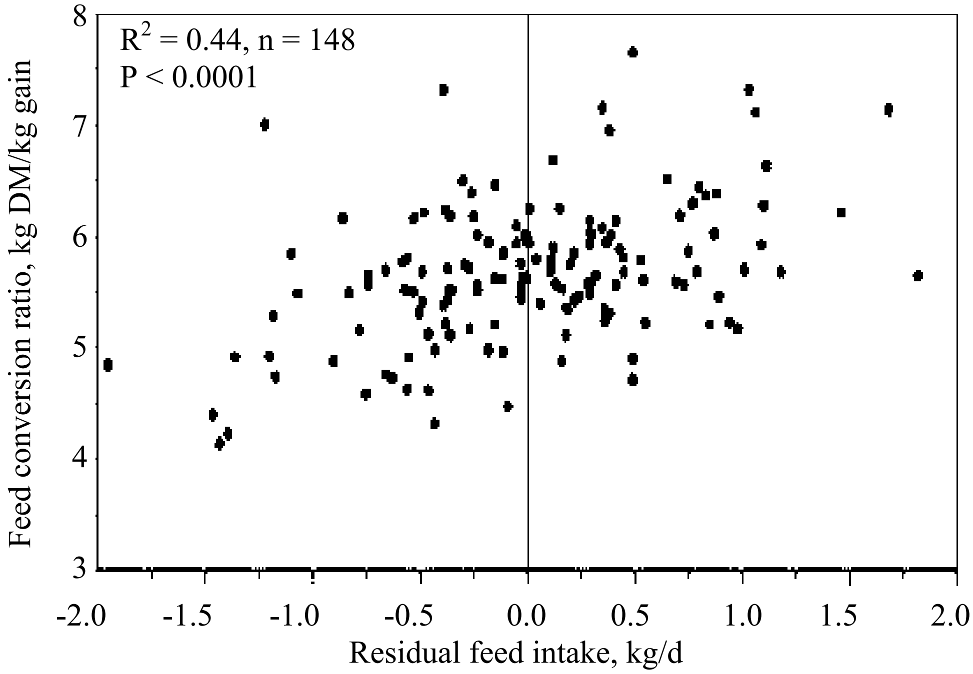

Figure 1. The relationship between RFI and FCR (Basarab, 2002).

Table 1. Phenotypic correlation between feed conversion ratio and residual feed intake

Breed	Phenotypic Correlation	Source
British	0.51	Arthur et al., 1997
British	0.47	Arthur et al., 1996
Charolais	0.85	Arthur et al., 2001b
Angus	0.53	Arthur et al., 2001a
Crossbred[1]	0.49	Carstens et al., 2002
British	0.61	Herd and Bishop, 1999
Multiple[2]	0.43	Liu et al., 2000
British[3]	0.41	Arthur et al., 2003
British[4]	0.43	Arthur et al., 2003

[1] Braunvieh-sired progeny of four breed rotation program using Angus, Simmental, Hereford, and Braunvieh breeds.
[2] Eight breeds evaluated consisting of: Blonde d' Aquitane, Charolais, Gelbvieh, Maine-Anjou, Saler, Simmental, Beef synthetic and Dairy synthetic.
[3,4] Bulls and heifers from same study denoted as 3 and 4, respectively.

Measuring feed intake and efficiency on growing animals and then selecting based on these traits is more practical than measuring these traits on mature animals. Archer et al. (2002) found that intake-related traits have a strong genetic relationship from post-weaning to maturity, suggesting that intake regulating processes are similar post-weaning to adult.

The expense of measuring feed efficiency is considerable, especially if feed intake is measured using Calan gate feeders or individual pens. Archer and Bergh (2000) demonstrated that the duration of performance tests could be reduced from 112 d to 70-84 d with little impact on the accuracy of measuring feed intake, ADG, FCR, or RFI. Archer and Barwick (1999) reported that measuring RFI was not profitable when the cost of measuring this trait exceeded $150 in a grass-fed target market. However, in breeding schemes that target high-quality beef production systems, the expense of measuring RFI was profitable at all testing cost levels evaluated (Archer and Barwick, 1999). If more efficient breeding schemes were implemented, profit may be possible even with measurement costs exceeding $150 in a grass-fed target market. The model used for this study was a “whole industry” perspective. The beef industry typically has separate owners for the breeding and commercial sectors. This poses the problem of breeders paying for the testing costs and commercial producers reaping the benefits of more efficient cattle. However, by breeders selling RFI tested bulls there may be an opportunity to increase market share.

Residual Gain. Another measurement of feed efficiency proposed by Koch et al. (1963) involves the use of a statistical model to adjust growth rate for individual differences in feed intake and BW, which is known as residual gain (RG). Residual gain is calculated as the difference between actual and expected ADG from linear regression of ADG on $BW^{0.75}$ and DMI. Cattle with a high RG (more efficient) will gain more than expected for their BW and feed intake. On the other hand, cattle with a low RG (less efficient) will gain less than expected for their BW and feed intake. Ferrell et al. (2003) determined RG of feedlot steers using initial BW instead of mid-test $BW^{0.75}$ while consuming a high-concentrate diet for 39 or 74 d, and found that five of 93 steers identified as more efficient based on RG, were 18 kg heavier at the beginning of the testing period and gained 0.41 kg/d faster than the mean.

Multi-trait selection indices that include growth traits and RFI may prove useful for rapid improvement of feed efficiency in beef cattle (Liu et al., 2000). The use of biological and economic parameters to determine index weights of feed efficiency, growth, and other traits could maximize profitability (Arthur et al, 2001a).

Genetics of Feed Efficiency

Breed Variation in Feed Efficiency Traits. Many studies have shown how breed can impact feed efficiency measurements. Chewning et al. (1990) reported breed differences in FCR of bulls fed a high concentrate diets for 140 d. In the first phase of this study, Hereford bulls (7.17) had lower FCR ($P < 0.05$) than Angus bulls (7.81), with Charolais (7.30) and Santa Gertrudis bulls (7.60) being intermediate. In the second phase of this study, Charolais (6.68), Maine-Anjou (6.73) and Simmental (7.10) bulls were more efficient than Angus and *bos indicus* composite bulls demonstrating that larger frame Continental breeds are usually more efficient when FCR was compared at a constant days on feed (DOF). In contrast, FCR of Simmental feedlot steers fed a high concentrate diet had higher FCR than Red Angus steers when fed to a common 8 to 10 mm of 12th rib fat estimated by ultrasound (Laborde et al., 2001). Myers et al. (1999b) found that ¾ Simmental X ¼ Angus cross-bred early-weaned steers tended ($P = 0.09$) to have higher gain:feed ratios and DMI during the growing phase (consuming either high-concentrate diet ad-libitum or on pasture with supplement) compared to ¾ Angus X ¼ Simmental steers of similar age. During the finishing phase of this study, all steers were fed a high-concentrate diet to a fat-constant endpoint and did not differ in feedlot gain:feed ratio, DMI or ADG.

In crossbreeding systems, heterosis may also play a role in improving feed efficiency. Comerford et al. (1991) measured FCR in feedlot steers from diallel matings of Simmental, Limousin, Polled Hereford and Brahman cattle. Diallel matings include all possible crosses among the four breeds including purebred and reciprocal crosses. This study found that heterosis improved FCR in all crosses except Limousin X Hereford.

Stage of Maturity Effects on Breed Variation in Feed Efficiency Traits. The Beef Improvement Federation (2002) recommends that post-weaning feed efficiency data be adjusted to a constant carcass fat endpoint in order to account for potential differences stage of maturity among cattle breeds. Urick et al. (1991) found that steers from Hereford dams sired by Continental breeds (Simmental, Pinzgauer and Tarentaise) were more efficient than Angus-sired steers when FCR was evaluated on an age-constant (382 d) or weight-constant (400 kg) basis. However, when FCR was adjusted to a common backfat endpoint (12.7 mm), Angus-sired steers were more efficient than Pinzgauer- and Tarentaise-sired steers with no difference between Angus- and Simmental-sired steers. Comerford et al. (1991) performed a similar study comparing unadjusted FCR to FCR adjusted to an age-constant (460 d) and fat-constant (8.0 mm) basis. In this study, the effect of sire breed on unadjusted FCR was significant, but sire breed did not affect FCR when adjusted to a fat-constant or age-constant endpoint. Bishop et al. (1991) found that adjusting FCR to a fat-constant endpoint reduced the genetic correlation between FCR and adjusted weaning wt, ADG and BW. These studies show that differences in feed efficiency among breeds may be related to frame size and predominant type of tissue (fat versus lean) accretion during efficiency measurement.

Within Breed Variation in Feed Efficiency Traits

Arthur et al. (1996) found that significant genetic variation exists for feed intake and RFI among individual animals as well as among sire progeny groups. In this study, heifers from Angus, Hereford and Shorthorn cows underwent a 120-d post-weaning performance test and consumed a high roughage pelleted diet. Individual RFI ranged from -1.53 to 1.68 kg/d. Genetic correlations between RFI and ADG are near zero meaning RFI is genetically independent of growth rate (Brelin and Brannang, 1982; Korver et al., 1991; Archer et al., 1998; Herd and Bishop, 2000; Arthur et al., 2001a, 2001b). However, genetic correlations between RFI and feed intake (FI) range from

0.38 to 0.83 (Archer et al., 1998; Korver et al., 1991) meaning inefficient cattle identified using RFI as a measure of efficiency have greater feed intakes. This suggests that variation in RFI may represent the variation between FI and growth, and by applying selection pressure against RFI genetic improvements in feed efficiency could be accomplished without affecting growth rate. Feed conversion ratio, on the other hand, has been shown to be negatively correlated genetically with growth rate (Brelin and Brannang, 1982; Korver et al., 1991; Archer et al., 1998; Herd and Bishop, 2000; Arthur et al. 2001a and 2001b; Bishop et al., 1991; MacNeil et al., 1991; Koots et al., 1994a and 1994b). These correlations range from -0.43 to -0.93. With large negative correlations between FCR and ADG, applying selection pressure against FCR may lead to larger mature size of cattle and increase feed required for maintenance thus depleting any economic benefit from selecting cattle for low FCR. Archer et al. (1998) reported a genetic correlation between RFI and BW of -0.25 in Angus bulls and heifers suggesting that more efficient cattle identified by low RFI may have greater BW. In contrast, Arthur et al. (2001b) reported a genetic correlation of 0.32 between BW and RFI in Charolais bulls which suggests that the relationship between BW and RFI is unclear. Other genetic correlations between RFI and BW are 0.03 (Korver et al., 1991), 0.22 (Herd and Bishop, 2000) and -0.06 (Arthur et al., 2001a). Genetic correlations between FCR and BW range from -0.60 (Koots et al., 1994b) to 0.46 (Korver et al., 1991).

Response to selection is dependent upon both genetic variance as well as heritability of the trait (Crews et al., 2003). Heritability estimates of RFI in cattle suggest that it is a moderately heritable trait (Table 2). These heritability estimates range from 0.16 to 0.46. Arthur et al. (2001c) evaluated postweaning growth and feed efficiency traits of calves derived from five years of divergent selection for RFI. Approximately two generations of selection were achieved in the low and high RFI selection lines consisting of heifers with negative RFI values bred to the 3 to 6 lowest RFI sires dependent upon year and heifers with positive RFI values bred to the 3 to 6 highest RFI sires, respectively. After 5 years of selection based on RFI, progeny from the high RFI selection line had 12.8% higher feed intakes and 18.2% higher FCR compared to progeny from the low RFI selection line, but selection lines did not differ in ADG, or yearling BW.

Feed Efficiency and Body Composition

Many researchers have evaluated possible relationships between RFI and measurements and/or estimates of body composition. One consideration that must be addressed prior to the adoption of RFI as a selection criterion is whether RFI selection has any negative associative effects with other production or performance traits. For instance, if selecting animals based on low RFI coincides with a significant reduction in longissimus muscle area, then RFI selection would be detrimental to carcass yield grade. However, phenotypic correlations show that RFI has little or no bearing on growth or longissimus muscle area, and displays only a slight decrease in subcutaneous fat depth, therefore, selecting animals based on RFI is unlikely to exhibit undesirable responses in performance traits of growing animals (Arthur et al., 1997).

Table 2. Heritability of feed efficiency measures and genetic correlations with performance traits

			-----------Genetic correlation coefficients-------------							
	-------h^2--------		-------ADG-------		--------BW--------		---------FI---------		FCR	
Breed	RFI	FCR	RFI	FCR	RFI	FCR	RFI	FCR	RFI	Source
Swedish Red	0.27	0.35	-0.08	-0.93	NR	NR	NR	-0.82	0.01	Brelin and Brannang, 1982
Dairy type	0.22	0.18	0.00	-0.77	0.03	0.46	0.83	0.70	0.82	Korver et al., 1991
British	0.46	NR	0.02	NR	-0.25	NR	0.38	NR	NR	Archer et al., 1998
Hereford	0.16	0.17	0.09	NR	0.22	NR	0.64	NR	0.70	Herd and Bishop, 2000
Charolais	0.39	0.46	-0.10	-0.46	0.32	0.24	0.79	0.85	0.85	Arthur et al., 2001b
Angus	0.38	0.32	-0.04	-0.62	-0.06	-0.01	0.69	0.31	0.66	Arthur et al., 2001a
Angus		NR		-0.66		-0.41		-0.26		Bishop et al., 1991
Hereford cross		0.26		-0.43		-0.03		0.31		MacNeil et al., 1991
Multiple		0.32		-0.67		-0.60		0.71		Koots et al., 1994a,b

In Braunvieh-sired steers, RFI and FCR were not correlated phenotypically with longissimus muscle area or intramuscular fat percentage (Carstens et al., 2002). Arthur et al. (1997) found that RFI was not correlated with longissimus muscle area, but was correlated with subcutaneous fat depth. Similar results were observed by Arthur et al. (1996) where phenotypic correlations between RFI and subcutaneous fat depth suggest lower RFI may be associated with decreased deposition of subcutaneous fat. However, Herd and Bishop (2000) observed negative phenotypic and genetic correlations between RFI and carcass lean content and lean growth rate which suggest that selection of animals based on RFI may slightly increase carcass leanness. Maynard (1998) demonstrated that progeny of low RFI animals had less subcutaneous fat when compared to progeny of high RFI animals. Correlations between sire estimated breeding values (EBV) for RFI and ultrasonic estimates of subcutaneous fat thickness and longissimus muscle area suggest changes in body composition and composition in gain may result if animal selection is based solely on RFI (Richardson et al., 2001). Jensen et al. (1991) observed FCR to be positively correlated genetically with percentage of fat in the carcass of Holstein Fresian and Brown Swiss half-siblings.

Basarab et al. (2003) compared RFI calculated using a base model that included mid-test $BW^{0.75}$ and ADG as independent variables with RFI calculated using the base model and ultrasound measurements of carcass fatness as independent variables. Including gain in empty body fat and water during the performance study as independent variables in the base RFI model slightly improved the R-square value of the model from 0.71 to 0.76, but did not significantly alter the ranking of steers compared to the base

RFI model. Likewise, including gain in 12th rib fat thickness and gain in marbling score as independent variables improved the R-square value of the model from 0.71 to 0.74. Arthur et al. (2003) evaluated the use of ultrasound measurements of body composition in RFI models and found that R-square values were improved 3.6 and 4.4 percentage points by the inclusion of rump fat thickness, and rump fat thickness with longissimus muscle area as independent variables. They concluded that the re-ranking of animals using body composition parameters in the RFI model was not great enough to establish these as part of the model. With ongoing RFI selection programs, genetic relationships between feed efficiency and subcutaneous fat thickness, longissimus muscle area, and dressing percentage should be monitored (Herd et al., 2003).

Feedlot Feed Efficiency and Previous Nutritional Status

One of the limitations to measuring feed efficiency traits in commercial bull-test facilities is that growth and feed efficiency traits can be influenced by previous nutritional status. Cattle exposed to periods of nutritional restriction will exhibit compensatory gains once adequate nutrition is provided. Cattle exhibiting compensatory growth have been reported to have increased feed intakes (Drouillard et al., 1991), decreased rates of fat deposition (Carstens et al., 1991) and decreased maintenance energy requirements (Sainz et al., 1995), resulting in improved feed efficiencies at similar carcass-weight end points. Fox et al. (1972) conducted a study comparing feed efficiency in Hereford steers fed a high-concentrate diet continuously to steers fed a diet formulated to maintain BW for either 154 or 190 d prior to being fed a high-concentrate diet to a common BW end-point. They found that steers previously restricted to maintain BW for 154 or 190 d had lower FCR (DM feed/kg gain) and higher ADG during the finishing period compared to steers fed a high-concentrate diet continuously. Ferrell et al. (1986) found that lambs fed at a higher plane of nutrition for 42 days lead to higher maintenance requirements during the next 42 days. Because animals may reduce their maintenance requirement by nutritional restriction, it could be possible to improve feed efficiency in the finishing phase of beef production using different methods of backgrounding and pre-weaning rearing. Creep-feeding calves prior to weaning is a popular practice among many cow-calf producers, especially for producers that sell their animals at weaning. Myers et al. (1999a) found that creep-fed steers had 32% faster pre-weaning ADG, but did not differ in feedlot ADG, gain:feed or DMI when compared to non creep-fed steers at a common 12th rib fat endpoint. Phillips et al. (1991) evaluated the effect of pre-weaning stocking rate on post-weaning performance as well as the effect of different backgrounding pastures on feedlot performance. They found that pre-weaning stocking rate had no effect on growing or finishing phase ADG. In this study, calves from three consecutive calving seasons were evaluated each year and were on feed until they reached a visual appraisal of grading USDA low choice. Calves backgrounded on winter wheat pasture had 100% greater growing phase ADG and 11.6% greater initial feedlot BW, but had 11.5% higher feedlot FCR, 8.7% lower feedlot ADG and similar final BW compared to calves backgrounded on native range (Phillips et al., 1991). Choat et al., (2003) found that feedlot ADG and gain:feed ratio were 9.0 and 11.0% greater, respectively, for calves previously backgrounded on native range vs calves previously backgrounded on winter wheat pasture. However, no differences in final yield grade or quality grade were found between steers due to backgrounding forage treatment.

Other methods of backgrounding use a limit-fed or programmed intake of high concentrate diets. Steers given ad-libitum access to high concentrate diets during the growing phase of production had lower ($P < 0.05$) ADG, DMI, and gain:feed ratios during the finishing phase than did steers previously fed a high-forage diet ad-libitum or limit-fed a high-grain diet during the growing phase (Sainz et al., 1995). Fluharty et al. (2000) demonstrated that Angus crossbred steers fed programmed intake levels of a high-concentrate diet for the first 112 DOF and then fed ad-libitum to harvest had 20% higher gain:feed ratios, 7% higher DMI and 32% greater ADG from d 113 to harvest when compared to steers offered ad-libitum access for the entire feeding period at a common BW endpoint. In contrast, Schoonmaker et al. (2003) found that Angus X Simmental cross-bred steers from 4 different backgrounding strategies (high-concentrate, high-roughage and limit-fed concentrate targeted to gain 0.8 and 1.2 kg/d) did not differ in finishing phase gain:feed ratio, ADG, DMI or BW at slaughter, but did differ in DOF when fed to a common 12th rib fat endpoint. These results suggest that improvements in feed efficiency during growth compensation are not as evident when compared at fat-constant endpoints.

More recently, producers have implemented early-weaning programs to allow more rapid recovery of cows from parturition to re-breeding. Early-weaned steers backgrounded on pasture with a supplement had 64% lower growing phase ADG, 9.4% higher feedlot ADG, 7.3% higher gain:feed ratios, but did not differ in feedlot DMI when compared to early-weaned steers provided ad-libitum access to high concentrate diets at weaning (Myers et al., 1999b). Wertz et al. (2001) found that early-weaned Angus X Simmental cross-bred heifers limit-fed a 90% concentrate diet at weaning had greater growing and finishing phase gain:feed ratios when compared to early-weaned heifers provided ad-libitum access to a 25% concentrate diet. When comparing early-weaned (177 days of age) steers to normal-weaned steers (231 days of age), Myers et al. (1999a) found that early-weaning improved feedlot gain:feed ratio by 9.7%. However, the early-weaned steers had 7.2% lower feedlot ADG and 5.2% lower DMI. In another study, early-weaned steers either limit-fed or given ad-libitum access to a concentrate diet at weaning had higher feedlot gain:feed ratio and lower feedlot DMI than did normal weaned steers or early-weaned steers given ad-libitum access to a forage diet at weaning (Schoonmaker et al., 2004).

These studies clearly show that previous plane of nutrition can have profound effects on feed efficiency during the finishing phase. This presents a challenge to measuring feed efficiency in bulls at commercial bull-test facilities where cattle coming in are from multiple ranches or farms and have been fed many different types of diets. However, Herd and Bishop (2000) found that normal weaned bulls (168 d of age) had improved ADG and FCR when evaluated from 200 to 400 d of age compared to early weaned bulls (84 d of age), but these management systems did not differ in RFI as a measure of efficiency. The results of Herd and Bishop (2000) suggest that RFI may be less affected by previous plane of nutrition compared to FCR.

EXPERIMENT 1

Introduction

For many years, beef cattle have been selected primarily on growth traits such as weaning and yearling weights, and feedlot ADG. As new technologies have been implemented, the process of selecting breeding stock has become more complex. The wide spread use of expected progeny differences (EPD) by the seedstock industry has lead to significant improvements in growth traits, and more recently, the industry has begun to focus on carcass quality traits. However, current selection programs have not taken input costs into consideration, even though feed inputs represent the single largest variable cost in producing beef. The ability to identify cattle that consume less feed without compromising performance or carcass quality would substantially improve profitability as well as reduce the environmental impact of beef production systems.

Feed efficiency has traditionally been measured as FCR, which is feed intake divided by weight gain. Feed conversion ratio is a gross measure of feed efficiency in that it does not attempt to account for differences in requirements for maintenance and growth (Arthur et al. 2001a; Brelin and Brannang, 1982; Mrode et al. 1990). An alternative method of measuring feed efficiency is RFI. This feed efficiency trait allows selection of more efficient cattle without the concurrent increases in mature size that would occur if selection pressure were applied against FCR (Arthur et al. 2001a and 2001b; Bishop et al. 1991). Residual feed intake measures the variation in feed intake beyond that needed to support maintenance and growth requirements, and is calculated as the difference between actual feed intake and the feed an animal is expected to consume based on its BW and ADG. Cattle that eat less than expected for their BW and ADG have negative RFI, which equates to improved feed efficiency. Objectives of this experiment were to: 1) characterize RFI in growing bulls, and 2) examine the relationships between RFI and performance, fertility, temperament, and body composition traits. This study was performed at the research center at McGregor, TX.

Materials and Methods

Experimental Animals. Bonsmara bulls (N = 68) obtained from the Chapman Ranch (Amarillo, TX) were used in this experiment. Nineteen sire progeny groups were represented ranging in size from one to 11 bulls per progeny group, but seven of 19 progeny groups had only one bull represented. The bulls originated from a ranch in New Mexico and were vaccinated with Bovashield 4 (Pfizer Animal Health) at weaning and again 3 wk later with Cattlemaster 4 (Pfizer Animal Health), Clostridial 7-Way with Haemophilus somnus and vitamin E. Average 205 d adjusted weaning weights of the bulls were 183 ± 20 kg. The bulls averaged 256 ± 5 d of age when they arrived at the McGregor Research Center. Upon arrival, bulls were weighed, dehorned and given Cydectin pour-on (Fort Dodge Animal Health, Overland Park, Kansas). Bulls were stratified by BW and randomly assigned to pens (four bulls per pen) equipped with Calan gate feeders. During a 35-d adaptation period, bulls were adapted to the experimental diet and trained to eat from Calan gate feeders. The experimental diet (Table 3) included cottonseed hulls, dry rolled corn, ground milo, cottonseed meal, molasses, and a vitamin/trace mineral premix and was formulated for growing bulls to gain 1.0 kg/d. Fifty percent of the cottonseed hulls were included in pelleted form to facilitate mixing of this high roughage diet (Table 3).

Performance Study. Individual feed intakes and BW were measured weekly for 70 d. Feed offerings were recorded and provided once daily at approximately 07:30. Bulls were fed to have approximately 0.5 kg of feed refusals remaining each day. Feed refusals were collected and weighed weekly to determine individual feed intakes. Samples of the experimental diet were obtained weekly and a composite sample sent to the Dairy One Forage Laboratory, Inc., Ithaca, NY for chemical analysis.

Measurements of Body Composition and Temperament. Frame scores (1 to 10) were recorded on d 0, and body condition scores (1 to 5) and hip heights were recorded on d 0 and 70 of the performance study. On d 0 and 70 of the study, ultrasound measurements of 12th rib and rump fat thickness, longissimus muscle area and percentage intramuscular fat were obtained using a Scanner 200 real-time ultrasound unit (Pie Medical Equipment Co., Maastrict, The Netherlands) equipped with an 18 cm, 3.5 MHz linear array transducer. Rump fat images were obtained at the juncture of the gluteus medius and biceps femoris muscles between the hook and pin bones parallel to the backbone.

Table 3. Experimental diet

Diet	Amount
Ingredients[a]	
Cottonseed hulls (pelleted)	25.0
Cottonseed hulls (loose)	25.0
Cottonseed meal	14.5
Dry rolled corn	13.5
Ground milo	13.5
Molasses	6.0
Premix[b]	2.5
Nutrients[cd]	
Dry Matter, %	91.6
Crude Protein, %	12.4
Metabolizable Energy, Mcal/kg	1.70
Acid detergent fiber, %	43.0
Neutral detergent fiber,%	52.2
Calcium, %	0.65
Phosphorus, %	0.30
Magnesium, %	0.26
Iron, ppm	120
Zinc, ppm	64.0
Copper, ppm	15.0

[a]Ingredients expressed as percent of diet on an as-fed basis.
[b]Vitamin/trace mineral premix formulated to provide (concentration in diet) 0.3 ppm Se, 0.69 ppm I, 0.15 ppm Co, 3300 IU/kg Vitamin A, and 113.3 IU/kg Vitamin E.
[c]Nutrients expresses as percent of diet on a dry-matter basis.
[d]Nutrient content based on lab analysis performed by Dairy One Forage Laboratory, Inc., Ithaca, NY.

Temperament of bulls was evaluated using two subjective scores on d 0 of the study. Chute temperament scores (1 being docile to 5 being very aggressive) were evaluated while bulls were restrained in a squeeze chute. Pen temperament scores (1 being docile and 5 being very aggressive) were evaluated as bulls returned from the processing facility to their assigned pen. Temperament of bulls was also evaluated by measuring exit velocity on d -35, 0 and 70 of the experiment. Exit velocity (Figure 2) was measured as the speed (m/sec) the bulls traversed a fixed distance of 1.83 m upon exiting a squeeze chute as described by Burrow et al. (1988).

Breeding Soundness Examinations. Breeding soundness examinations were performed on d 5 and 61 following the 70-d performance study. Scrotal circumference was measured on d 0 and 70 of the experiment and on d 61 following the end of the 70-d performance study. During the first breeding soundness examination, bulls were evaluated on extension of penis, semen consistency, and progressive motility. During the second breeding soundness examination, bulls were tested for percent abnormal sperm and progressive motility. For each breeding soundness examination, bulls were classified as unsatisfactory, questionable, or satisfactory for breeding. Penile extension (full, partial or none), semen consistency (milky, moderate or thin), sperm abnormality (> 30 % abnormal or < 30 % abnormal) and breeding soundness (satisfactory, questionable or unsatisfactory) were recorded as discrete variables.

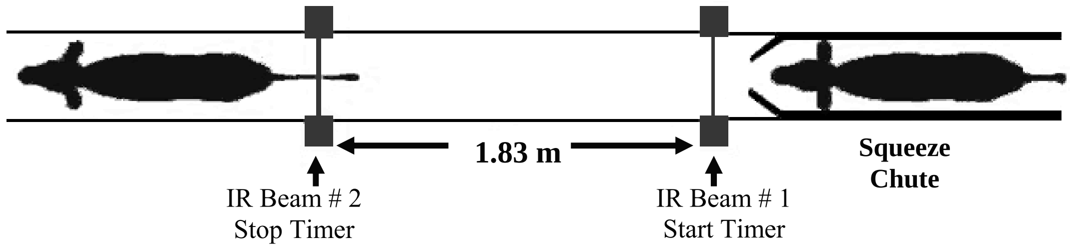

Figure 2. Illustration demonstrating how exit velocity is measured. (Curley et al., 2004)

Statistical Analysis. The regression procedure (Proc REG) of SAS (1999) was used to regress BW on d on test to more accurately determine ADG. This regression model was also used to determine initial (d 0) and final (d 70) BW, and mid-test $BW^{0.75}$. Feed conversion ratio was calculated as kg DM feed/kg BW gain. Residual feed intake (RFI_I) was calculated as the difference between actual and expected feed intake from the following linear regression model:

$$\text{DM intake} = \beta_0 + \beta_1 \text{ mid-test } BW^{0.75} + \beta_2 \text{ ADG} + \text{error}$$

The inclusion of carcass parameters into the RFI model was evaluated using the base model plus ultrasound measurements as independent variables to determine additional RFI models used for analysis. Based upon this analysis, RFI_{II} was determined using the base model with the addition of gain in 12th rib fat thickness over the 70-d performance study as an independent variable, and RFI_{III} was determined using the base model and d-70 intramuscular fat percentage as an independent variable. In addition, residual gain (RG) was calculated as the difference between actual and expected ADG using the following linear regression model:

$$\text{ADG} = \beta_0 + \beta_1 \text{ mid-test } BW^{0.75} + \beta_2 \text{ DMI} + \text{error}$$

Partial correlations were performed using the Proc CORR procedure of SAS (1999) to determine significant relationships between feed efficiency traits and performance, body composition, temperament and breeding soundness examination traits. Bulls were ranked by RFI_I and assigned to low, medium and high RFI_I groups that were < -0.5 SD, $\pm$ 0.5 SD, and > 0.5 SD from the mean RFI_I of 0.0 ± 1.09 SD kg/d, respectively. The least-squares means option of the GLM procedure of SAS (1999) was used to evaluate differences in body composition traits, temperament, and performance traits among RFI_I groups. The chi-square option of Proc FREQ (SAS, 1999) was used to observe differences in extension of penis, semen consistency, sperm abnormality, or breeding soundness classification between RFI_I groups of bulls.

Results and Discussion

Performance and Feed Efficiency. Three bulls died during the study, and three bulls were excluded from analysis because their intakes were periodically reduced due complications with bloat. Overall ADG, average daily DMI, and RFI_I for the 70-d trial were 1.77 (SD = 0.20), 11.1 (SD = 1.67), and 0.00 (SD = 1.09) kg/d, respectively (Table 4). Dry matter intakes were phenotypically correlated ($P < 0.001$) with ADG ($r = 0.66$), initial BW ($r = 0.56$), final BW ($r = 0.71$) and mid-test $BW^{0.75}$ ($r = 0.48$). As expected, RFI was not phenotypically correlated with initial BW, final BW, or ADG as these traits were included as independent variables to calculate RFI. These observations are in agreement with previous studies, which found RFI was phenotypically independent of BW and ADG (Herd and Bishop, 2000; Arthur et al., 2001a, 2001b; Carstens et al., 2002).

Table 4. Number of animals, means, standard deviations (SD), minimums and maximums of traits evaluated

Trait†	No. of animals	Mean	SD	Min	Max
RFI_I, kg/d	62	0.00	1.09	-3.78	2.46
RFI_{II}, kg/d	62	0.00	1.04	-3.66	2.46
RFI_{III}, kg/d	62	0.00	1.02	-3.42	2.37
Residual gain, kg/d	62	0.00	0.15	-0.27	0.32
Initial BW, kg	62	258	30.4	204	331
Final BW, kg	62	382	37.2	304	473
Mid-test $BW^{0.75}$, kg	62	75.6	5.87	63.6	89.6
Average daily gain, kg/d	62	1.77	0.20	1.18	2.18
Dry matter intake, kg/d	62	11.1	1.67	7.4	14.4
Feed conversion ratio, kg/kg	62	6.27	0.73	4.44	7.87
Initial frame score	62	5.42	0.88	4.00	7.00
Initial hip height, cm	62	117	3.48	110	126
Final hip height, cm	62	124	3.41	117	132
Change hip height, cm	62	6.60	1.54	3.81	10.16
Initial body condition score	62	5.56	0.45	5.00	6.50
Final body condition score	62	5.23	0.40	4.50	6.00
Initial 12^{th} rib fat, mm	62	3.28	0.55	2.29	4.32
Final 12^{th} rib fat, mm	62	5.61	0.68	3.81	6.86
Change 12^{th} rib fat, mm	62	2.34	0.94	0.51	4.57
Initial rump fat, mm	62	3.42	0.58	2.29	4.57
Final rump fat, mm	62	5.49	0.75	3.81	7.62
Change rump fat, mm	62	2.06	0.70	0.51	3.56
Initial intramuscular fat, %	62	2.67	0.31	2.26	3.59
Final intramuscular fat, %	62	2.66	0.29	2.35	3.54
Change intramuscular fat, %	62	-0.01	0.39	-1.00	1.07
Initial longissimus muscle area, cm^2	62	41.9	4.99	31.6	54.1
Final longissimus muscle area, cm^2	62	61.6	8.01	47.3	86.7
Change longissimus muscle area, cm^2	62	19.7	5.97	7.1	32.6
Initial exit velocity, m/s	62	2.75	0.57	1.42	3.94
Final exit velocity, m/s	62	2.15	0.60	1.08	3.37
Initial chute score	62	1.17	0.36	1.00	2.00
Initial pen score	62	2.55	0.69	2.00	4.00
Initial scrotal circumference, cm	62	24.5	2.50	19.0	29.3
Final scrotal circumference, cm	62	31.0	2.29	26.1	36.0
Change scrotal circumference, cm	62	6.43	1.33	4.00	10.00
Scrotal circumference 61 d post-study, cm	62	32.6	2.19	26.0	37.0
Motility 5 d post-study, %	58	23.7	18.0	0.0	70.0
Motility 61 d post-study, %	57	66.4	12.3	20.0	80.0

† Initial and final traits were measured on d 0 and 70 of the performance study, respectively.

Including ultrasound measurements of carcass traits into the RFI model revealed that gain in 12th rib fat thickness (backfat) over the 70-d study (RFI_{II}) as an independent variable improved the R-square of the model by 3.5 percentage points, which was more than any other single trait. However, including both gain in backfat and final intramuscular fat (RFI_{III}) improved the R-square of the model by an additional 1.9 percentage points (Table 5). The addition of these carcass parameters to the RFI model did not substantially alter correlated responses between RFI and other traits measured in this study.

Arthur et al. (2003) found that including subcutaneous fat thickness measured at the rump in the RFI model improved the R-square by 3.6% in bulls and 1.8% in heifers (British breed). However, including longissimus muscle area estimates in the RFI model, only improved R-square by 0.8 and 0.3% in bulls and heifers, respectively. Basarab et al. (2003) evaluated RFI models that included gain in empty body fat and water, and gain in ultrasound subcutaneous fat thickness and marbling score. R-square values of these models were not reported, but adjusting for these independent variables did affect correlated responses with other carcass parameters.

Table 5. Summary statistics for the inclusion of carcass parameters in the RFI model

Model[a]	SS[b]	MSE[c]	R-square
Base model (RFI_I)	98.4	1.22	0.577
Base model and FBF	101.6	1.19	0.596
Base model and FIM	102.1	1.18	0.599
Base model and FREA	98.4	1.24	0.577
Base model and CBF (RFI_{II})	104.4	1.14	0.612
Base model and CIM	101.2	1.19	0.594
Base model and CREA	99.4	1.23	0.583
Base model, CBF and FIM (RFI_{III})	107.5	1.10	0.631
Base model, CBF and FREA	104.5	1.16	0.613

[a]Model used to determine RFI.
[b]Sum of squares for the model.
[c]Mean squared error of the model.

In the current study, RG was correlated ($P < 0.01$) with ADG ($r = 0.75$), but not with IBW, FBW or DMI (Table 6). RFI_I was phenotypically correlated ($P < 0.001$) with FCR ($r = 0.85$), which was larger than correlations observed by Carstens et al. (2002), Arthur et al. (2001a and 2001b), and Herd and Bishop (2000). The current study revealed a tendency ($P = 0.15$) for FCR to be negatively correlated with ADG. Carstens et al. (2002) and Arthur et al. (2001a) also observed negative correlations between FCR and ADG, but the correlations were considerably greater than the current study. Figure 3 shows the relationship between feed efficiency traits and growth rate for the current study. Feed conversion ratio and RFI_I were both positively correlated ($P < 0.001$) with DMI ($r = 0.62$ and $r = 0.65$, respectively) suggesting that more efficient animals consume less feed on a daily basis. Arthur et al. (2001b) reported that DMI were phenotypically correlated with FCR (0.48) and RFI (Table 7).

Table 6. Phenotypic correlations of performance traits

Trait[a]	FBW	ADG	DMI	FCR	RFI_I	RFI_{II}	RFI_{III}	RG
IBW	0.93**	0.29*	0.56**	0.41**	0.00	0.00	0.00	-0.18
FBW		0.62**	0.71**	0.26*	0.00	0.00	0.00	0.14
ADG			0.66**	-0.18	0.00	0.00	0.00	0.75**
DMI				0.62**	0.65**	0.62**	0.61**	0.00
FCR					0.85**	0.81**	0.79**	-0.78**
RFI_I						0.96**	0.93**	-0.51**
RFI_{II}							0.98**	-0.49**
RFI_{III}								-0.48**

[a]IBW = initial BW; FBW = final BW; ADG = average daily gain; DMI = dry matter intake; FCR = feed conversion ratio; RFI = residual feed intake; RG = residual gain.

* $P < 0.05$.

** $P < 0.01$.

Table 7. Phenotypic correlations between feed efficiency and growth performance traits in cattle

Trait[a]	Current Study	Carstens, et al. 2002	Arthur et al., 2001a	Arthur et al., 2001b	Herd & Bishop, 2000
			---RFI_I---		
ADG	0.00	0.001	-0.06	0.01	-0.01
BW	0.00	0.002	0.02	0.03	-0.01
FI	0.65	0.59	0.72	0.60	0.70
FCR	0.85	0.49	0.53	0.57	0.61
			---FCR---		
ADG	-0.18	-0.72	-0.74	-0.54	NR
BW	0.33	-0.10	0.16	-0.08	NR
FI	0.62	0.01	0.23	0.48	NR

NR = Not reported
[a]FI = feed intake; RFI_I = residual feed intake; FCR = feed conversion ratio

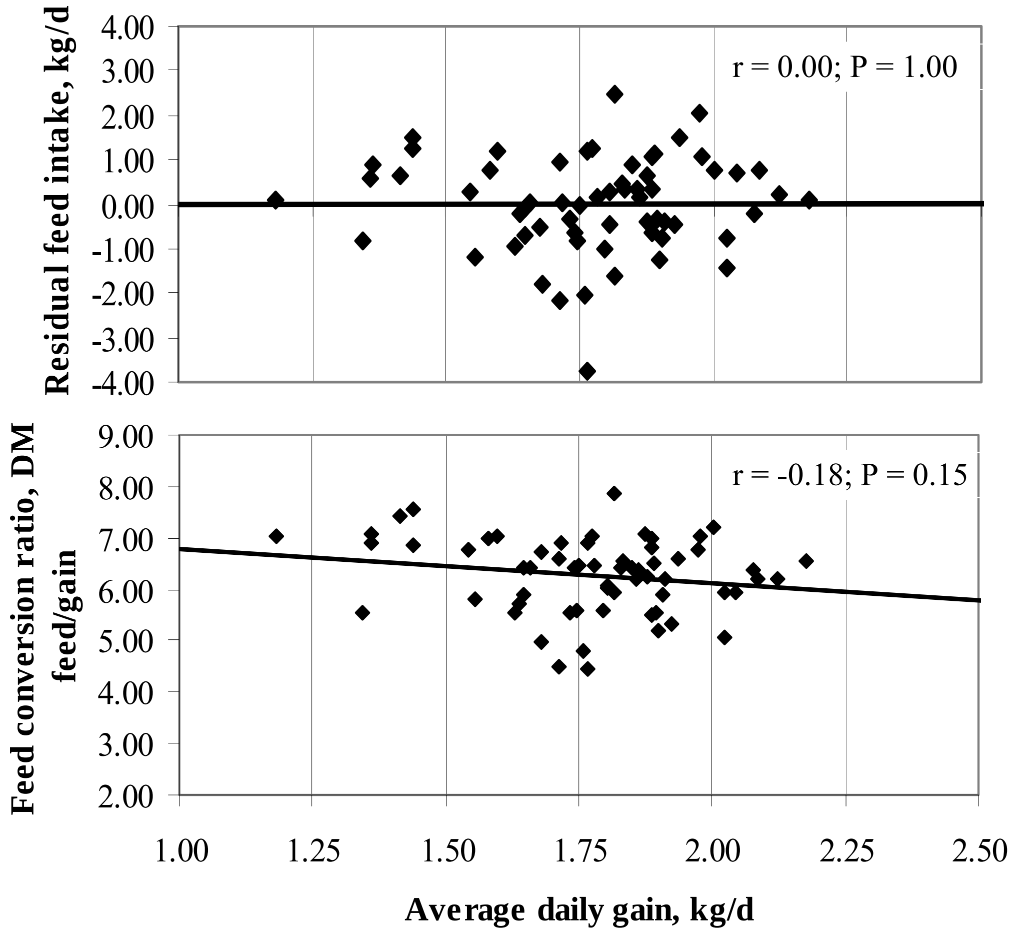

Figure 3. Relationship between RFI_I and FCR, and ADG in growing bulls.

Average RFI_I for bulls identified as having low (< 0.5 SD below the mean), medium (± 0.5 SD from the mean) and high (> 0.5 SD above the mean) RFI were -1.32, -0.03, and 1.11 ± 0.13 kg/d, respectively. Growth rate, initial BW, and final BW were not statistically different for low, medium, and high RFI_I bulls. However, high RFI_I bulls (less efficient) consumed 25% more ($P < 0.001$) DMI than low RFI_I (more efficient) bulls, resulting in the high RFI_I bulls having 26% higher FCR than the low RFI_I bulls (Table 8). Likewise, in steers fed a roughage-based pelleted diet, steers with high RFI (> 0.5 SD above the mean) consumed 21% more DMI than steers with low RFI (< 0.5 SD below the mean) even though ADG and BW were similar between the two groups (Carstens et al., 2002). In steers fed a high grain diet, Basarab et al. (2003) found that when RFI was calculated including gain in backfat thickness and marbling, low RFI steers (> 0.5 SD of the mean) consumed 11.6% more DMI than low RFI steers (< 0.5 SD below the mean).

Table 8. Characterization of performance traits in bulls with low, medium, and high RFI_I

	RFI_I GROUP				
Trait[a]	Low	Med	High	SE	P-value
Number	17	24	21	-	-
Age at initiation of test, d	291	291	289	2.63	0.76
RFI_I, kg/d	-1.32[b]	-0.03[c]	1.11[d]	0.13	< 0.01
Initial BW, kg	252	265	254	7.37	0.35
Final BW, kg	376	391	377	9.01	0.32
MBS, kg	74.5	77.0	74.8	1.42	0.32
ADG, kg/d	1.76	1.80	1.75	0.05	0.71
DMI, kg/d	9.59[b]	11.3[c]	12.0[c]	0.34	< 0.01
FCR, kg/kg	5.45[b]	6.31[c]	6.89[d]	0.11	< 0.01

[a]RFI_I = residual feed intake; MBS = mid-test $BW^{0.75}$; DMI = dry matter intake; FCR = feed conversion ratio (DM feed/ADG).

[bcd] Values within row with different superscript differ significantly ($P < 0.01$).

Body Composition Traits. Frame score was not phenotypically correlated ($P > 0.20$) with ADG or feed efficiency traits, but was correlated ($P < 0.05$) with BW ($r = 0.49$), DMI ($r = 0.25$) and longissimus muscle area ($r = 0.37$). Hip height (HH) measured on d 0 and 70, and gain in HH over the 70-d performance study were not correlated with either of the RFI efficiency traits. Basarab et al. (2003) also found that RFI was not correlated with HH or gain in HH of steers fed a high-grain diet for 112 d prior to slaughter. In the current study, initial and final HH did not differ between bulls with low and high RFI_I, but bulls with medium RFI_I had larger ($P < 0.05$) initial and final HH than bulls with high RFI_I. Residual gain was not correlated with initial or final HH, but was correlated ($P < 0.01$) with gain in HH during the 70-d performance study. Initial ($P < 0.05$) and final ($P < 0.10$) HH, but not gain in HH during the 70 d performance study, were moderately correlated with FCR.

Body condition score (BCS) was not correlated with RFI_I on d 0 or 70. Feed conversion ratio tended ($P < 0.10$) to be positively correlated with d-0 BCS ($r = 0.23$), but not with d-70 BCS ($r = 0.03$). However, backfat measured on d 0 and 70 was not correlated with FCR (Table 9), which is consistent with Arthur et al. (2001a). RFI_I tended to be negatively correlated with initial backfat ($r = -0.22$; $P = 0.08$), but positively with final backfat ($r = 0.20$; $P = 0.11$). Consequently, gain in backfat during the 70-d performance study was positively correlated with RFI_I ($r = 0.28$; $P = 0.03$) (Table 9).

Basarab et al. (2003) reported a tendency for RFI_I to be correlated ($r = 0.15$; $P = 0.07$) with initial backfat and gain in backfat over the testing period ($r = 0.22$; $P < 0.01$), but not with backfat measured at the termination of the study ($r = 0.02$; $P = 0.82$). Carstens et al. (2002) found that RFI was correlated with initial ($r = 0.11$; $P = 0.15$) and final ($r = 0.22$; $P < 0.01$) backfat. Arthur et al. (2001a) observed genetic correlations between backfat and RFI of 0.17 in Angus bulls and heifers measured postweaning. In contrast, Crews et al. (2003) reported genetic correlations between backfat at slaughter and growing (75% roughage diet) phase and finishing (20% roughage diet) phase RFI of -0.24 and -0.09, respectively. Basarab et al. (2003) observed phenotypic correlations between RFI and final percent empty body fat ($r = 0.12$; $P = 0.14$) and gain in percent empty body fat ($r = 0.26$; $P < 0.01$).

In the current study, bulls with low RFI_I tended to have ($P < 0.10$) more backfat on d 0, but less backfat on d 70 of the performance study compared to bulls with high RFI_I. As a result, gain in backfat during the 70-d performance study was less ($P < 0.05$) for bulls with low RFI_I versus bulls with high RFI_I. As expected, RFI_{II} and RFI_{III} were not correlated with initial, final or gain in backfat during the 70-d performance study. Basarab et al. (2003) found that by including gain in empty body fat and water, and gain in ultrasound fat thickness and gain in marbling score in the RFI model, correlations between RFI and carcass fatness parameters became less significant. This suggests that applying selection pressure against RFI adjusted for carcass fat may have less effects on body composition. Gain in backfat over the 70 d performance study was not correlated with FCR. Initial, final and gain in subcutaneous fat depth measured at the rump was not correlated ($P > 0.15$) with either measure of feed efficiency. This is consistent with Arthur et al. (2001a) who found that feed efficiency measurements were not genetically correlated with rump fat.

Percent intramuscular fat of the longissimus muscle (IM fat) on d 0 was not correlated with FCR, however, final IM fat and change in IM fat over the 70-d performance study was phenotypically correlated ($P < 0.05$) with FCR ($r = 0.25$ and 0.26, respectively). RFI_I and RFI_{II} tended ($P < 0.10$) to be phenotypically correlated with d 70 IM fat ($r = 0.23$ and 0.22, respectively), but was not correlated with initial IM fat or change in IM fat over the 70 d performance study period. However, RFI_{III} was not correlated with initial, final or gain IM fat. Likewise, Carstens et al. (2002) found no correlation between RFI and final IM fat. Basarab et al. (2003) observed a correlation between RFI and change in marbling score ($r = 0.22$; $P < 0.01$) over the testing period, and a tendency ($P = 0.11$) for RFI to be correlated with marbling score at the termination of their study ($r = 0.13$). In the current study, RFI_I groups did not differ significantly in IM fat on d 0, but low RFI_I bulls, had 6.5% less ($P < 0.05$) IM fat than high RFI_I bulls on d 70. These results suggest that cattle with low RFI_I may tend to have a slower rate of lipid accretion. In contrast, Crews et al. (2003) found negative correlations between RFI and marbling scores suggesting that low RFI cattle may have a faster rate of lipid accretion.

Ultrasound estimates of longissimus muscle area (REA) on d 0 and 70 were not correlated with either of the RFI efficiency traits or FCR (Table 9). This is consistent with Carstens et al. (2002) and Arthur et al. (2001a), which both used ultrasound estimates of REA and did not observe any significant correlations between REA and RFI or FCR. Crews et al. (2003) observed genetic correlations between REA and growing and finishing phase RFI of 0.15 and 0.52, respectively. Basarab et al. (2003) found no correlation ($P < 0.30$) between RFI and initial, final REA, or gain in REA over a 120-d performance study, but did observed a tendency for RFI to be correlated ($r = -0.14$; $P = 0.09$) with final empty body protein. However, gain in empty body protein was not correlated with RFI ($P = 0.16$). In the current study, RFI_I groups did not differ significantly in REA on d 0 or 70, nor did they differ in gain in REA over the 70 d performance study (Table 10). Residual gain was phenotypically correlated ($P < 0.05$) with final REA and change in REA over the 70 d performance study (Table 9).

Estimates of Temperament. Chute scores were not correlated with any of the performance or feed efficiency traits. However, pen scores were negatively correlated ($P < 0.01$) with BW and ADG, and tended ($P < 0.10$) to be correlated with DMI (Table 11). Pen scores were not correlated with RFI_I or FCR, however, pen scores were correlated ($P = 0.05$) with RG.

Table 9. Phenotypic correlations between feed efficiency and body composition traits in growing bulls

Trait[a]	FCR	RFI_I	RFI_{II}	RFI_{III}	RG
Initial frame score	0.16	-0.07	-0.12	-0.14	-0.05
Initial hip height, cm	0.25*	-0.06	-0.06	-0.06	-0.10
Final hip height, cm	0.22†	-0.01	-0.03	-0.03	0.02
Change hip height, cm	-0.09	0.11	0.07	0.07	0.27**
Initial BCS	0.23†	0.02	-0.03	-0.06	-0.14
Final BCS	0.03	-0.16	-0.07	-0.06	-0.15
Initial backfat, mm	-0.03	-0.22†	-0.04	-0.05	0.05
Final backfat, mm	0.11	0.20	0.03	-0.04	0.12
Change backfat, mm	0.09	0.28*	0.00	-0.00	0.06
Initial rump fat, cm	0.17	0.01	-0.01	-0.01	-0.07
Final rump fat, cm	0.05	0.03	-0.13	-0.17	0.12
Change rump fat, cm	-0.09	0.03	-0.13	-0.18	0.19
Initial IM fat, %	-0.10	-0.03	0.07	0.03	0.03
Final IM fat, %	0.25*	0.23†	0.22†	-0.00	-0.12
Change IM fat, %	0.26*	0.19	0.11	-0.02	-0.11
Initial REA, cm^2	0.20	-0.14	-0.14	-0.16	-0.13
Final REA, cm^2	0.15	-0.01	-0.01	-0.03	0.26*
Change REA, cm^2	0.03	0.10	0.09	0.09	0.33**

[a]BCS = body condition score; REA = longissimus muscle area; IM fat = intramuscular fat of the longissimus muscle; backfat = 12th rib fat thickness.

†$P < 0.10$.

*$P < 0.05$.

**$P < 0.01$.

Table 10. Characterization of body composition traits in bulls with low, medium and high RFI_I

	RFI_I GROUP				
Trait[a]	Low	Med	High	SE	P-Value
Number	17	24	21	-	-
Initial frame score	5.29	5.67	5.24	0.21	0.21
Initial hip height, cm	116.8[bc]	118.9[c]	116.2[b]	0.81	0.03
Final hip height, cm	123.3[bc]	125.3[c]	123.0[b]	0.80	0.05
Change hip height, cm	6.57	6.46	6.77	0.38	0.79
Initial BCS	5.53	5.58	5.57	0.11	0.93
Final BCS	5.26	5.23	5.20	0.10	0.90
Initial backfat, mm	3.50[f]	3.23[ef]	3.15[e]	0.13	0.14
Final backfat, mm	5.36[e]	5.66[ef]	5.76[f]	0.16	0.19
Change backfat, mm	1.87[b]	2.43[c]	2.60[c]	0.22	0.05
Initial rump fat, cm	3.41	3.50	3.34	0.14	0.64
Final rump fat, cm	5.39	5.52	5.52	0.18	0.84
Change rump fat, cm	1.99	2.02	2.18	0.17	0.66
Initial IM fat, %	2.77	2.63	2.64	0.07	0.33
Final IM fat, %	2.60[b]	2.59[b]	2.78[c]	0.07	0.06
Change IM fat, %	-0.16[b]	-0.05[bc]	0.14[c]	0.09	0.06
Initial REA, cm^2	42.9	41.7	41.4	1.22	0.65
Final REA, cm^2	60.9	62.2	61.4	1.77	0.87
Change REA, cm^2	18.0	20.5	20.0	1.45	0.42

[a]BCS = body condition score; REA = longissimus muscle area; IM fat = intramuscular fat within the longissimus muscle; backfat = 12th rib fat thickness.

[bcd]Values within row with different superscript differ significantly ($P < 0.05$).

[efg]Values within row with different superscript tend to differ ($P < 0.10$).

Initial exit velocity was negatively correlated (P < 0.05) with initial and final BW, DMI, and ADG. Exit velocity measured on d 70 was negatively correlated (P < 0.05) with final BW, DMI, ADG, and tended to be correlated (P < 0.10) with initial BW (Table 11). These results are consistent with Burrow and Dillon (1997) who found that animals with slow exit velocity gained more weight and achieved heavier slaughter and carcass weights. Initial and final exit velocities were not correlated (P < 0.30) with RFI_I, FCR or RG (Table 11). Bulls with low RFI_I did not differ from bulls with high RFI_I for any of the temperament traits evaluated (Table 12). These results suggest that slower growth rates of cattle with aggressive temperaments as assessed by exit velocity are a function of decreased feed intake not decreased feed efficiency.

Breeding Soundness Examinations. Gain in scrotal circumference in bulls during the 70-d performance study was positively correlated (P < 0.05) with ADG and final BW, but not with DMI. Scrotal circumference was not correlated with RFI_I on d 0, 70 or 61 d following the 70-d performance study. In contrast, initial scrotal circumference was positively correlated with FCR and negatively correlated with RG (Table 13). This would suggest that selection for improved feed efficiency using FCR or RG may lead to smaller scrotal cirumference and potentially later maturing calves. However, Arthur et al. (2001a) did not observe significant genetic correlations between scrotal cirumference and RFI or FCR.

Table 11. Phenotypic correlations between temperament traits, and growth and feed efficiency traits in Bonsmara bulls

Trait[a]	IEV	FEV	ICS	IPS
Initial BW, kg	-0.28*	-0.24†	-0.09	-0.32**
Final BW, kg	-0.32**	-0.30*	-0.10	-0.40**
DMI, kg/d	-0.34**	-0.26*	-0.06	-0.23†
ADG, kg/d	-0.25*	-0.27*	-0.09	-0.36**
RFI_I, kg/d	-0.15	-0.03	0.04	0.15
RG, kg/d	-0.02	-0.12	-0.06	-0.25†
FCR, kg/kg	-0.17	-0.07	0.01	0.09

[a]DMI = dry matter intake; RFI_I = residual feed intake; RG = residual gain; FCR = feed conversion ratio (DM feed/ADG); IEV = initial exit velocity; FEV = final exit velocity; ICS = initial chute score; IPS = initial pen score.

† $P < 0.10$.

* $P < 0.05$.

** $P < 0.01$.

Table 12. Characterization of temperament traits in bulls with low, medium and high RFI_I

	RFI_I GROUP				
Trait	Low	Med	High	SE	P-Value
Number	17	24	21	-	-
Initial exit velocity, m/s	2.97	2.62	2.71	0.14	0.13
Final exit velocity, m/s	2.25	2.04	2.18	0.15	0.52
Initial chute score	1.15	1.17	1.19	0.09	0.94
Initial pen score	2.47	2.46	2.71	0.17	0.41

Table 13. Phenotypic correlations between feed efficiency and bull fertility traits

Trait[a]	RFI_I	RG	FCR	ADG	FBW
Initial scrotal circumference, cm	0.10	-0.33**	0.39**	-0.02	0.49**
Final scrotal circumference, cm	0.01	-0.14	0.25*	0.14	0.56**
Change in scrotal circumference, cm	-0.17	0.38**	-0.31*	0.29*	0.04
Scrotal circumference 61 d post-study, cm	-0.07	-0.13	0.21	0.11	0.52**
Sperm motility 5 d post-study, %	-0.11	0.02	-0.07	-0.06	-0.05
Sperm motility 61 d post-study, %	0.07	0.12	-0.05	0.16	0.04

[a]RFI_I = residual feed intake; RG = residual gain; FCR = feed conversion ratio (DM feed/ADG); FBW = final BW.

† $P < 0.10$.

* $P < 0.05$.

** $P < 0.01$.

Table 14. Characterization of bull fertility traits in bulls with low, medium and high RFI_I

	RFI_I GROUP				
Trait	Low	Med	High	SE	P-Value
Initial scrotal circumference, cm	24.1	24.4	24.9	0.61	0.62
Final scrotal circumference, cm	31.0	31.0	31.1	0.56	1.00
Scrotal circumference 61 d post study, cm	32.4	32.8	32.5	0.54	0.82
Sperm motility 5 d post-trial, %	25.3	25.0	20.8	4.55	0.70
Sperm motility 61 d post-trial, %	63.7	68.6	66.0	3.20	0.49

In the current study, sperm motility measured at 5 and 61 d post-trial was not correlated with any measure of feed efficiency (Table 13). Bulls in the low, medium and high RFI groups did not differ for any of the afore mentioned fertility traits (Table 14). Chi-square analysis revealed no significant differences between RFI_I groups in penile extension, semen consistency, sperm abnormality, or overall breeding soundness (Table 15). These results suggest that applying selection pressure against RFI_I would not affect breeding soundness of bulls.

Conclusions

Residual feed intake was phenotypically correlated with FCR while remaining independent of BW and ADG in Bonsmara bulls. Bulls with low RFI consumed 2.43 kg/d (20%) less feed than bulls with high RFI even though gains and final BW were similar for both groups of bulls. Residual feed intake was not correlated with longissimus muscle area, but tended to be positively correlated with subcutaneous fat thickness at the 12th rib and percent intramuscular fat of the longissimus muscle. Exit velocity, an estimate of temperament, was negatively correlated with feed intake and ADG, but was not correlated with any of the feed efficiency traits measured in this study. RFI was not related to any bull fertility traits, but FCR and RG were correlated with scrotal circumference.

Feed efficiency traits have been shown to be moderately heritable in previous studies. Results from this study suggest that applying selection pressure against RFI could increase feed utilization efficiency without detrimental effects on feedlot performance, muscling, temperament or bull fertility traits.

Table 15. Percent of animals within RFI_I group in each fertility trait classification and chi-square values

Trait	RFI_I GROUP			Chi-sq	P-value
	Low	Med	High		
Number of animals	17	24	21		
Penile extension, 5 d post-trial				1.77	0.78
Full	52.9	58.3	42.9		
Partial	17.7	16.7	14.3		
None	29.4	25.0	42.9		
Semen consistency, 5 d post-trial				3.65	0.46
Milky	0.0	8.7	0.0		
Moderate	70.6	56.5	65.0		
Thin	29.4	34.8	35.0		
Sperm abnormality, 61 d post-trial				3.18	0.20
> 30 % abnormal	13.3	0.0	5.0		
< 30 % abnormal	86.7	100	95.0		
Breeding soundness, 61 d post-trial				1.84	0.77
Satisfactory	76.5	87.5	90.5		
Questionable	11.8	4.2	4.8		
Unsatisfactory	11.8	8.3	4.8		

EXPERIMENT 2

Introduction

Typically, cattle exposed to periods of nutritional restriction will exhibit compensatory gains once adequate nutrition is provided. Fox et al. (1972) observed improved feed efficiency (DM feed/kg gain) in compensating steers. Cattle exhibiting compensatory growth have been reported to have increased feed intakes (Drouillard, et al. 1991), decreased rates of fat deposition (Carstens et al., 1991) and decreased maintenance energy requirements (Sainz et al., 1995), resulting in improved feed efficiencies and leaner carcasses at similar carcass-weight end points. However, recent studies have demonstrated that compensatory growth responses are not always evident (Schoonmaker et al., 2003)

Renewed interest in selection for more efficient cattle has prompted the search for alternative measures of feed efficiency. The traditional measure of feed efficiency (feed:gain ratio) is negatively correlated with ADG (r_g = -0.67) and mature weight (r_p = -0.15) (Koots et al., 1994). RFI is also a moderately heritable measure of feed efficiency, but is genetically independent of growth and BW (Arthur et al., 2001b). Herd and Bishop (2000) concluded that RFI was not effected by pre-test conditions as much as other feed efficiency measures, BW and ADG.

This experiment is a culmination of two studies performed at the Research and Extension Centers at Overton and Amarillo, TX. Calves in this study were assigned pre-weaning and stocker treatments at the research center at Overton and then finished at the research center in Amarillo. The objectives of experiment 2 were to: 1) examine the effects of stocker supplementation on FCR and RFI efficiency measures in finishing calves, and 2) characterize relationships between feed efficiency measurements, and performance and carcass traits in finishing calves.

Materials and Methods

Experimental Animals and Design. Fall-born, Simmental-sired calves (N = 132) from two consecutive calving seasons (1985 and 1986) were assigned to high, medium and low stocking rates pre-weaning at 151 ± 14 and 153 ± 16 d of age, respectively. Grazer cattle were used to adjust forage availability of the other treatments. Using analysis of pre-weaning ADG, medium and low stocking rate calves were combined to form the low pre-weaning group. High and medium pre-weaning groups consisted of calves assigned to high stocking rate and grazer calves, respectively. At weaning (260 ± 12.5 d of age in 1985; 269 ± 16.0 d of age in 1986), calves were assigned to stocker supplementation treatments while grazing bermudagrass pasture. Multiple stocker supplements were used during the stocker-phase as described by Grigsby et al. (1989). These supplements implemented the use of a condensed molasses block containing 31.6% crude protein (CMB), a condensed molasses block with fish meal containing 32.5% crude protein (FMB), a dry protein supplement containing 34.2% crude protein (DRY), DRY with 1.3 and 1.7% rumen-stable Methionine and Lysine containing 30.7% crude protein (DAA), fish meal with and without Rumensin (FIS and FMR), and SoyPlus (SoyPlus, West Central, P.O. Box 68, Ralston, IA) with fishmeal and Rumensin containing 44.4% crude protein (SOY). For analysis in this study, calves were grouped into three stocker treatments each year based upon ADG during the stocker phase independent of effects of pre-weaning stocking rate. Stocker treatments (ST) were no supplement (NS), low-intake (LP) and high-intake (HP) of a protein supplement. In 1985, calves in the NS treatment received CMB, FMB or no supplement (PAS). LP calves born in 1985 received DAA, and HP calves received DRY or FMR. In 1986, calves in the NS treatment received PAS. The LP calves born in 1986 received a CMB, and HP calves received FIS, FMR, or SOY. Calves grazed bermudagrass at similar stocking rates while receiving stocker supplementation from June to October each year. Upon feedlot entry (387 ± 12 d of age in 1985; 424 ± 16 d of age in 1986), calves were adapted to a feedlot diet and trained to eat from Pinpointer feeders for 28 d. Feedlot adaptation diets contained (as-fed basis) 35, 45, 65 and 75 % steam-flaked corn for d 1-7, 8-14, 15-21 and 22-28, respectively. The final feedlot diet (d 28 to harvest) consisted of 80% steam-flaked corn, 5% cottonseed hulls, 5% molasses and 10% supplement (as-fed basis). Individual feed intakes were measured daily, and BW was measured at 28-d intervals. In 1985, calves were harvested at 130, 158 or 185 d on feed (DOF); whereas, in 1986 calves were harvested at 150 or 213 DOF at a visual estimate of 1.0 cm of backfat. Carcass data were collected at slaughter by USDA graders at a commercial abattoir.

Statistical Analysis. Pre-weaning ADG was analyzed using Proc GLM and included independent effects of pre-weaning treatment or group, SEX and YR. Effects of stocker supplementation on stocker performance were analyzed within year and included SEX as an independent effect. Initial stocker BW among stocker treatments was analyzed using Proc GLM and included independent effects of SEX and YR. The effect of stocker treatment on stocker ADG was analyzed using initial stocker BW as a covariate to account for differences among stocker treatments. Initial and final feedlot BW, and ADG were determined using linear regression of BW on DOF. Residual feed intake (RFI_I) was calculated as the difference in actual DMI and expected DMI from the following linear regression model that included SEX, YR and DOF(YR) as independent effects.

$$DMI = \beta_0 + \beta_1 \text{ mid-test } BW^{0.75} + \beta_2 \text{ } ADG + \text{error}$$

RFI_{II} was calculated in a similar manner, but also included carcass 12th rib fat thickness as an independent variable. Residual gain (RG) was calculate as the difference between actual and expected ADG from the following linear regression model that included independent effects of DOF(YR), SEX and YR.

$$ADG = \beta_0 + \beta_1 \text{ mid-test } BW^{0.75} + \beta_2 \text{ } DMI + \text{error}$$

Feedlot data were analyzed using Proc GLM of SAS and included initial stocker BW as a covariate because pre-weaning treatments displayed differences in initial stocker-phase BW. Stocker treatment, SEX, YR and DOF(YR) were included in the model as main effects and any significant interactions were included as well. Partial correlations were determined using MANOVA function of GLM. Calves were ranked by RFI_I, separated into low, medium and high RFI_I groups that were < 0.5 SD, ± 0.5 SD and > 0.5 SD, respectively, from the mean RFI_I of 0.0 ± 0.77 kg/d. The least-squares means option of the GLM procedure of SAS (1999) was used to evaluate differences in performance or carcass traits among RFI_I groups.

Results and Discussion

Pre-weaning ADG for calves assigned to high, medium and low stocking rates, and for grazer calves are shown in Table 16. Low, medium, and high pre-weaning groups (PWG) consisted of calves assigned to low and medium stocking rates, grazer calves, and calves assigned to high stocking rates, respectively. Pre-weaning ADG of low, medium and high PWG are shown in Table 16. After weaning, calves were allotted by weight and visual condition score to multiple stocker supplements (Table 17). These supplements were then grouped into stocker treatments based upon stocker ADG independent of effects of pre-weaning treatment (Table 17). Average initial stocker BW for NS (N = 49), LP (N = 23) and HP (N = 60) calves 299, 286 and 278 ± 6 kg ($P < 0.01$), respectively. Because of these differences among stocker treatment groups, initial stocker BW was included as a covariate for analyzing stocker ADG, feedlot performance and carcass traits. Stocker ADG for NS, LP and HP calves were 0.44, 0.56 and 0.70 ± 0.03 kg/d ($P < 0.01$), respectively.

Table 16. Effect of pre-weaning treatment and group on pre-weaning ADG

Item	Number of steers	Number of heifers	Pre-weaning ADG, kg/d	SE
Pre-weaning treatment				
High stocking rate	12	10	0.92[a]	0.04
Med stocking rate	13	11	1.22[b]	0.04
Low stocking rate	11	10	1.28[b]	0.04
Grazer	28	37	0.99[a]	0.02
Pre-weaning group (current study)				
High	12	10	0.92[a]	0.04
Med	28	37	0.99[a]	0.02
Low	24	21	1.25[b]	0.03

[ab]Means within treatment or group without common superscript differ ($P < 0.05$)

Table 17. Effect of stocker supplementation on stocker performance

Supplementation	Number of calves	CP[a], %	Initial Stocker BW, kg	Stocker ADG, kg/d	Final Stocker BW, kg	Supp intake[a], kg/d	Stocker treatment[†]
Supplement; Year 1							
PAS	12	-	293[c]	0.44[b]	345[b]	0.00	NS
CMB	10	31.6	287[c]	0.47[b]	341[b]	0.20	NS
FMB	12	32.5	292[c]	0.51[b]	352[bc]	0.21	NS
DAA	12	30.7	286[c]	0.62[c]	358[bc]	1.00	LP
DRY	12	34.2	288[c]	0.70[c]	369[c]	0.87	HP
FMR	12	37.2	249[b]	0.84[c]	347[b]	0.51	HP
Supplement; Year 2							
PAS	15	-	308[c]	0.34[b]	343[bc]	0.00	NS
CMB	11	31.6	285[bc]	0.47[c]	335[b]	0.23	LP
FIS	11	35.8	290[bc]	0.62[d]	355[bc]	0.73	HP
FMR	13	37.2	284[bc]	0.68[d]	355[c]	0.38	HP
SOY	12	44.4	280[b]	0.70[d]	354[bc]	0.48	HP

[a]Crude protein and intake of supplements from Grigsby et al. (1989).
[bcd]Means within year without common superscript differ ($P < 0.05$).
[†]Used for current study.

Effect of Stocker Treatment on Feedlot Performance and Carcass Traits. Initial (d 0) feedlot BW of NS steers and heifers in year 1 were 10.3 and 6.4 % lower ($P < 0.01$) than HP steers and heifers, respectively. Initial feedlot BW of NS steers and heifers in year 2 were 8.2 and 4.9 % lower ($P < 0.05$) than HP steers and heifers, respectively. When feedlot BW was evaluated after the 28-d adaptation, NS steers and heifers were 6.9 and 4.7% lighter ($P < 0.05$) than HP steers and heifers during year 1, but not year 2. As expected, NS calves had 10% faster ($P < 0.05$) feedlot ADG than did HP supplemented calves for the entire feedlot period. Choat et al. (2003) found that calves backgrounded on native range having slower ADG during the growing phase had 9.0% faster gains during the finishing phase compared to calves backgrounded on winter wheat pasture. In the current study, excluding the 28-d adaptation period from analysis removed the treatment effect, but ADG were remained numerically higher for NS calves compared to HP calves.

The largest amount of compensatory growth is generally seen early in the realimentation period, by excluding the first 28 d from analysis, it may have removed some of the potential effects. Feedlot DMI and final BW were not affected by stocker treatments. Feedlot FCR appeared to be influenced more by stocker treatment when evaluated over the entire feedlot period versus excluding the 28-d adaptation period (Tables 18 and 19). Non-supplemented calves had an 8.5% lower ($P < 0.05$) FCR than HP calves when evaluated over the entire feedlot period (Table 18). These findings are consistent with Phillips et al. (1991), Fluharty et al. (2000) and Sainz et al. (1995) which reported improved feed efficiency expressed as a ratio in calves coming from treatments that limited growth rate when compared to calves from treatments that allowed faster growth rates. Excluding data from the 28-d adaptation period reduced this difference to 7.2% (P = 0.10) (Table 19). Year x supplement x sex interaction was significant for FCR because NS heifers in 1986 exhibited higher FCR than did HP heifers which was not expected. NS calves of 1985 and NS steers of 1986 all exhibited numerically lower FCR than HP calves of 1985 and steers of 1986. RFI_I was not affected (P > 0.15) by stocker treatment when calculated over the entire period or after the adaptation period. Herd and Bishop (2000) found that RFI appeared to be influenced less by pre-test conditions than did FCR. Residual gain was affected (P < 0.01) by stocker supplementation when evaluated for the whole feeding period, but not affected (P > 0.20) when evaluated from d 28 to harvest. Ferrell et al. (2003) found that FCR, RFI and RG were all affected by prior nutritional treatment.

Hot carcass weight, longissimus muscle area, KPH and quality grade of the calves were not affected by stocker treatment. Choat et al. (2003) found steers backgrounded on native range had 7.4% lighter hot carcass weights, 6.3% smaller longissimus muscle area and 9.2% less KPH than steers backgrounded on winter wheat pasture, but treatments not differ in backfat, yield grade or quality grade.

Table 18. Effect of stocker supplementation on feedlot performance and feed efficiency traits during the entire feedlot period

Item	Stocker Supplement			SE	P-value
	NS	LP	HP		
DMI, kg/d	7.86	8.30	7.74	0.24	0.12
ADG, kg/d	1.21^{b}	1.17^{ab}	1.10^{a}	0.04	0.04
Initial BW, kg*	300^{a}	318^{b}	324^{b}	3.75	< 0.01
Final BW, kg	501	513	507	7.52	0.41
FCR, kg/kg*	6.59^{a}	7.22^{b}	7.20^{b}	0.25	0.03
RFI_{I}, kg/d*	-0.042	0.293	-0.085	0.184	0.17
RG, kg/d	0.063^{b}	-0.030^{a}	-0.047^{a}	0.034	< 0.01

*Significant interaction between year x supplement x sex.

[ab]Means differ ($P < 0.05$).

[cd]Means tend to differ ($P < 0.10$).

Table 19. Effects of stocker supplementation on feedlot performance and feed efficiency traits from d 28 to harvest

	Stocker Supplement				
Item	NS	LP	HP	SE	P-value
DMI, kg/d	8.29	8.61	8.19	0.25	0.31
ADG, kg/d	1.16	1.13	1.08	0.05	0.31
28-d BW, kg*	340[a]	357[b]	358[b]	4.97	< 0.01
Final BW, kg	499	511	506	7.39	0.36
FCR, kg/kg*	7.19	7.86	7.75	0.31	0.10
RFI_I, kg/d*	-0.001	0.162	-0.114	0.172	0.35
RG, kg/d	0.045	-0.016	-0.012	0.040	0.27

*Significant interaction between year x supplement x sex.
[ab]Means differ (P < 0.05).

In the current study, backfat and yield grade were greater ($P < 0.01$) for heifers consuming LP supplement compared to heifers receiving NS and HP supplement, however, stocker supplement did not affect back fat or yield grade in steers (Table 20). Schoonmaker et al. (2004) found that early-weaned steers provided ad-libitum access to a high-concentrate diet at weaning had smaller longissimus muscle area and lighter hot carcass weights compared to early-weaned steers given ad-libitum access to a high forage diet at weaning, but steers did not differ in yield grade or quality grade.

Feedlot Performance and Feed Efficiency. Overall feedlot ADG, DMI, RFI_I and FCR for the entire feedlot period were 1.17 ± 0.03, 7.93 ± 0.24, 0.00 ± 0.18 kg/d and 6.94 ± 0.25 kg DM/kg gain, respectively. Feedlot ADG, DMI, RFI_I and FCR from d 28 to harvest were 1.12 ± 0.05, 8.30 ± 0.25, 0.00 ± 0.17 kg/d and 7.58 ± 0.31 kg DM/kg gain, respectively. As expected, RFI_I was not correlated ($P > 0.20$) with BW or ADG, but was correlated ($P < 0.01$) with DMI ($r = 0.70$) and FCR ($r = 0.57$) (Table 21). These correlations are similar to those reported by Arthur et al. (1997).

Table 20. Effect of stocker supplementation on carcass traits

Item	Stocker Supplement NS	LP	HP	SE	P-Value
Hot carcass weight, kg	313	317	315	6.30	0.86
Backfat, cm*	0.74[a]	0.96[b]	0.69[a]	0.09	0.03
Longissimus muscle area, cm^2	88.0	83.4	86.9	1.99	0.15
KPH, %	1.52	1.61	1.55	0.10	0.74
USDA yield grade*	1.77[a]	2.26[b]	1.79[a]	0.10	0.01
USDA quality grade	3.85	3.61	3.59	0.16	0.17

[abc]Means differ ($P < 0.05$).
*Significant interaction between supplement x sex.

RFI_{II} did not exhibit any substantial differences in correlated responses with performance traits when compared to RFI_I (Table 21). Feed conversion ratio was negatively correlated ($P < 0.01$) with ADG and BW. Carstens et al. (2002) and Arthur et al. (2001a) found FCR to be negatively correlated with ADG and BW suggesting that applying selection pressure for improved FCR may lead to increased mature size and increased maintenance energy requirements. Residual gain was correlated ($P < 0.01$) with BW, ADG, FCR and RFI_I, but not with DMI (Table 21). Calves in the low, medium and high RFI_I groups did not exhibit significant differences in ADG or BW, but low RFI_I calves (more efficient) consumed 22% less feed and had 21% improved FCR versus high RFI_I calves (less efficient). These observations are consistent with Experiment 1. Age of the calves upon entry to the feedlot was correlated ($P < 0.05$) with FCR ($r = 0.22$), RG ($r = -0.29$) and ADG ($r = -0.21$) calculated after the adaptation period. Calves in the low, medium and high RFI_I groups did not differ in age (Table 22).

Table 21. Partial correlations of performance and feed efficiency traits measured from d 28 to harvest (above diagonal) and over the entire feedlot period (below diagonal)

Trait[a]	IBW	FBW	ADG	DMI	FCR	RFI_I	RFI_{II}	RG
28 BW		0.45**	-0.20*	0.23*	0.38**	0.12	0.14	-0.39**
FBW	0.32**		0.75**	0.69*	-0.46**	0.01	0.03	0.48**
ADG	-0.17†	0.85**		0.62**	-0.77**	-0.05	-0.05	0.83**
DMI	0.18†	0.64**	0.59**		-0.04	0.70**	0.66**	0.07
FCR	0.36**	-0.45**	-0.63**	0.21*		0.57**	0.58**	-0.96**
RFI_I	0.12	0.03	-0.01	0.77**	0.71**		0.99**	-0.57**
RFI_{II}	0.10	0.05	0.02	0.75**	0.69**	0.99**		-0.58**
RG	-0.43**	0.55**	0.82**	0.03	-0.92**	-0.53**	-0.49**	

[a]IBW = initial feedlot BW; 28 BW = post-adaptation BW; FBW = final BW; MBS = mid-test $BW^{0.75}$; ADG = average daily gain; DMI = dry matter intake; RFI = residual feed intake; FCR = feed conversion ratio.

*P < 0.05.

**P < 0.01.

†P < 0.10.

Table 22. Characterization of feedlot performance traits measured from d 28 to harvest in calves with low, medium, and high RFI_I

	RFI_I Group				
Item	Low	Med	High	SE	P-Value
Number	36	58	37	-	-
Age at feedlot entry	404	404	406	3.95	0.87
DMI, kg/d	7.15^{a}	8.37^{b}	9.13^{c}	0.26	< 0.01
ADG, kg/d	1.09	1.13	1.10	0.04	0.75
Post-adaptation BW, kg	350	353	353	6.57	0.90
Final BW, kg	505	500	504	6.45	0.85
FCR, kg DM/kg gain	6.72^{a}	7.50^{b}	8.49^{c}	0.20	< 0.01
RFI_I, kg/d	-0.97^{a}	0.05^{b}	0.53^{c}	0.59	< 0.01

^{abc}Means differ ($P < 0.05$).

Carcass Composition and Quality. RFI_I calculated after the 28-d adaptation was not correlated ($P > 0.40$) with longissimus muscle area, KPH, yield grade or quality grade, but tended ($P < 0.10$) to be correlated with back fat (Table 23). RFI_I also tended to be correlated ($P < 0.10$) with hot carcass weight ($r = 0.16$) and dressing percentage ($r = 0.16$) when calculated after the 28-d adaptation (Table 23). However, hot carcass weight and dressing percentage were not correlated ($P > 0.10$) with RFI_I calculated for the entire feedlot period. Calves having low, medium and high RFI_I did not differ in hot carcass weight or any other carcass parameters (Table 24). RFI_{II} was not correlated with backfat, REA, KPH, yield grade or quality grade, but tended ($P < 0.10$) to be correlated with dressing percentage ($r = 0.16$). Feed conversion ratio was correlated ($P < 0.01$) with hot carcass weight ($r = -0.26$) and tended ($P < 0.10$) to be correlated with longissimus muscle area ($r = -0.18$) suggesting that cattle with lower FCR have larger carcasses (Table 23). Residual gain was correlated ($P < 0.05$) with hot carcass weight and dressing percentage, and tended ($P < 0.10$) to be correlated with REA and KPH (Table 23). Age upon feedlot entry was correlated with backfat ($r = 0.22$; $P < 0.05$), but not with any other carcass parameters.

Table 23. Partial correlations between feedlot performance and carcass traits measured from d 28 to harvest

Trait[a]	HCW	BF	REA	KPH	DP	YG	QG
28 BW	0.42**	0.35**	0.19†	0.13	0.20*	0.23*	0.47**
FBW	0.75**	0.40**	0.39**	0.36**	0.02	0.24*	0.34**
ADG	0.51**	0.19†	0.32**	0.28**	-0.11	0.07	0.04
DMI	0.59**	0.35**	0.33**	0.28**	0.08	0.17†	0.17†
FCR	-0.27**	-0.04	-0.18†	-0.15	0.16†	-0.02	0.01
RFI_I	0.17†	0.18†	0.08	0.06	0.17†	0.07	0.02
RFI_{II}	0.11	0.10	0.07	0.02	0.16†	0.02	0.00
RG	0.25**	-0.00	0.19†	0.17†	-0.21*	-0.01	-0.07

[a]28 BW = post-adaptation BW; FBW = final BW; MBS = mid-test $BW^{0.75}$; ADG = average daily gain; DMI = dry matter intake; FCR = feed conversion ratio; RFI = residual feed intake; HCW = hot carcass weight; BF = back fat; REA = longissimus muscle area; KPH = kidney, pelvic and heart fat; DP = dressing percent; YG = USDA yield grade; QG = USDA quality grade.

*$P < 0.05$.

**$P < 0.01$.

†$P < 0.10$.

Table 24. Characterization of carcass traits in calves with low, medium, and high RFI_I

	RFI_I GROUP				
Item	Low	Med	High	SE	P-Value
Number	36	58	37	-	-
Hot carcass weight, kg	309	312	313	4.96	0.82
Back fat, cm	0.63	0.76	0.77	0.07	0.27
Longissimus muscle area, cm^2	82.7	86.1	86.2	1.76	0.25
KPH, %	1.53	1.60	1.53	0.07	0.60
USDA yield grade	1.85	1.89	1.83	0.11	0.90
USDA quality grade	3.52	3.61	3.63	0.12	0.79

Conclusions

Stocker supplementation treatments affected growth performance during the grazing phase and carcass traits following the finishing phase. The stockers assigned to the NS treatment gained 10% faster over the entire finishing phase than stockers assigned to the HP supplement treatment. The NS stockers also had lower FCR and RG (more efficient) than HP stockers, although RFI, was not affected by stocker supplementation treatment. These results suggest that FCR and RG feed efficiency traits are influenced more by previous plane of nutrition than is RFI.

As expected, RFI was positively correlated phenotypically with DMI and FCR, while remaining independent of BW and ADG. Residual feed intake was not correlated with longissimus muscle area, KPH, yield grade or quality grade, but tended to be correlated with backfat suggesting that calves with low RFI were slightly leaner than calves with high RFI.

SUMMARY

Residual feed intake and FCR are moderately heritable traits with substantial variation among individual animals allowing for selection of animals to improve feed efficiency independent of growth. Although FCR and RFI are positively correlated genetically and phenotypically, FCR is negatively correlated with growth rate, whereas, RFI is not. In experiments 1 and 2, cattle with low RFI consumed 20 and 22% less feed on a daily basis than cattle with high RFI, even though no differences in ADG or BW were evident. In experiment 1, RFI was not related to bull fertility or temperament traits. However, lower RFI tended to be associated with lower levels of lipid accretion. Including ultrasound measurements as independent variables in the RFI model improved the R-square of the model, but the magnitude of this increase was small.

Research has shown that previous plane of nutrition can have profound effects on feed efficiency measurements. When evaluating performance of cattle for selection, particularly in a commercial setting, it is important that feed efficiency measurements not be biased by different nutritional backgrounds. Experiment 2 demonstrated that previous plane of nutrition had a greater influence on FCR as a measure of feed efficiency than on RFI. Together, these two experiments demonstrated that RFI can be a useful selection tool to decrease input costs of producing beef without affecting growth performance.

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APPENDIX A

Table A1. Pre-trial data collected 12/13/2002 for experiment 1

ID	Age, d	BW, kg	Exit Veloc, m/s	Chute score, 1-5	Pen score, 1-5	BCS, 1-5	Frame score, 1-10
20	277	536	2.58	1	1	5	6
21	277	586	2.12	1	1	5	7
22	277	514	1.81	1	1	5	6
24	271	480	2.21	1	1	5	5
25	269	473	2.38	1	1	6	5
27	265	508	1.93	1	1	6	5
28	265	546	2.19	1	1	5	6
29	265	574	3.33	1	1	6	6
30	265	630	1.67	1	1	6	6
34	264	483	2.47	1	1	5	4
35	263	492	3.72	1	1	6	5
39	263	421	2.38	1	1	5	4
41	262	520	1.58	1	1	5	6
42	262	556	1.93	1	1	5	7
44	261	522	2.30	1	1	6	5
45	261	476	2.74	1	1	5	6
46	261	568	2.51	1	1	6	6
47	261	532	2.88	1	1	6	5
48	260	522	1.94	1	1	5	6
49	260	516	2.70	1	1	5	5
51	260	510	1.77	1	1	5	7
52	260	428	1.65	2	1	5	5
57	260	409	2.03	1	1	5	6
58	259	417	3.29	1	1	6	5
60	259	460	2.46	1	1	6	5
63	259	502	2.52	1	1	5	6
65	259	475	3.00	1.5	1	5	6
69	258	447	2.60	1	1	6	5
70	258	524	2.18	1	1	5	5
71	258	592	2.06	1	1	6	6
73	258	449	1.46	1	1	5	6

Table A1. (continued)

ID	Age, d	BW, kg	Exit Veloc, m/s	Chute score, 1-5	Pen score, 1-5	BCS, 1-5	Frame score, 1-10
74	257	459	2.22	1	1	5	5
76	256	482	3.25	1.5	1	5	7
78	256	502	2.68	1	1	5	7
79	256	622	2.26	1	1	5	7
81	255	438	1.97	1	1	5	5
82	255	484	1.95	1	1	6	7
83	255	484	2.51	1	1	5	6
84	255	504	2.23	1	1	6	5
85	254	432	2.11	1	1	5	5
86	253	460	1.72	1	1	5	5
87	253	463	2.43	1	1	5	6
88	253	461	1.85	1	1	5	4
89	252	387	2.43	1	1	5	5
90	252	590	2.27	1	1	6	6
91	252	432	1.93	1	1	6	4
93	251	464	1.93	1	1	5	6
94	250	512	2.10	1	1	6	4
95	250	497	2.31	1.5	1	5	5
100	248	371	2.90	1	1	5	4
103	245	492	2.93	1	1	6	6
105	245	488	2.29	1	1	5	6
107	215	482	2.21	1	1	5	4
118	241	427	2.25	1	1	5	5
121	239	408	2.34	1	1	4	5
123	239	478	3.33	1	1	5	5
124	238	442	1.86	1.5	1	5	6
125	238	414	2.57	1	1	5	5
126	233	437	2.10	1	1	6	4
129	.	493	2.71	1	1	5	5
130	.	376	3.03	1	1	5	4
131	.	469	2.32	1	1	5	5

Table A2. Performance data for experiment 1

ID	Initial BW, kg	Final BW, kg	$BW^{.75}$, kg	Model ADG, kg/d	DMI, kg/d	FCR	RFI_I, kg/d	RFI_{II}	RFI_{III}	RG
20	302	422	83.03	1.72	11.8	6.89	0.01	0.33	0.56	-0.14
21	308	435	84.57	1.81	10.7	5.92	-1.61	-1.46	-1.64	0.04
22	284	415	80.85	1.88	11.7	6.23	-0.42	-0.35	-0.15	0.04
24	255	383	75.44	1.83	11.7	6.41	0.45	0.32	0.52	0.01
25	251	366	73.61	1.65	9.7	5.87	-0.72	-0.28	-0.33	-0.02
27	280	414	80.46	1.91	11.8	6.18	-0.38	-0.48	-0.22	0.07
28	297	436	83.78	1.98	13.9	7.03	1.05	1.38	0.93	-0.03
29	307	452	85.95	2.08	13.3	6.38	-0.23	0.37	-0.13	0.11
30	331	471	89.62	2.00	14.4	7.21	0.76	0.39	0.27	-0.06
34	249	375	74.17	1.80	10.0	5.57	-1.00	-0.50	-0.33	0.11
35	262	370	74.91	1.54	10.4	6.75	0.25	0.01	-0.15	-0.18
39	204	304	63.60	1.44	9.9	6.85	1.48	1.37	1.11	-0.20
41	285	427	81.92	2.02	12.1	5.96	-0.74	-0.89	-1.37	0.16
42	297	419	82.31	1.74	11.2	6.40	-0.65	-0.58	-0.33	-0.06
44	282	409	80.19	1.81	14.3	7.86	2.46	2.51	2.37	-0.20
45	245	357	72.19	1.60	11.2	7.02	1.19	0.66	0.56	-0.17
46	311	428	84.32	1.68	11.3	6.74	-0.51	-0.85	-0.76	-0.14
47	274	407	79.27	1.91	11.3	5.91	-0.77	-0.40	-0.73	0.11
48	283	407	80.07	1.77	7.8	4.44	-3.78	-3.66	-3.42	0.21
49	272	400	78.51	1.83	12.0	6.55	0.35	0.17	0.42	-0.02
51	266	396	77.56	1.86	11.8	6.35	0.17	0.11	0.15	0.03
52	233	365	71.84	1.89	10.4	5.51	-0.63	-0.95	-0.91	0.18
57	235	355	71.14	1.71	11.3	6.58	0.96	0.94	1.10	-0.06
58	214	334	67.42	1.71	7.7	4.48	-2.19	-1.98	-1.88	0.22
60	235	353	71.01	1.68	8.4	4.97	-1.83	-1.33	-1.19	0.12
63	275	397	78.51	1.75	11.3	6.48	-0.03	-0.16	-0.09	-0.05
65	232	368	72.11	1.93	12.7	6.58	1.48	1.09	0.88	0.05
69	233	359	71.34	1.80	11.0	6.09	0.30	0.40	0.59	0.05
70	265	397	77.56	1.89	12.8	6.80	1.07	1.37	1.40	-0.02
71	307	438	84.76	1.87	13.3	7.08	0.67	0.05	0.35	-0.09
73	236	366	72.25	1.85	11.8	6.40	0.88	0.54	0.43	0.03

Table A2. (continued)

ID	Initial BW, kg	Final BW, kg	$BW^{.75}$, kg	Model ADG, kg/d	DMI, kg/d	FCR	RFI_I, kg/d	RFI_{II}	RFI_{III}	RG
74	255	379	75.12	1.77	12.2	6.91	1.20	1.84	1.61	-0.09
76	247	330	69.99	1.18	8.3	7.02	0.07	0.54	0.26	-0.37
78	261	377	75.48	1.65	10.5	6.40	-0.07	-0.37	-0.30	-0.09
79	320	473	88.82	2.18	14.3	6.56	0.08	0.32	0.56	0.13
81	223	319	66.79	1.36	9.4	6.90	0.90	1.23	1.32	-0.26
82	261	372	75.09	1.58	11.1	7.00	0.74	-0.11	-0.75	-0.19
83	271	419	80.07	2.12	13.1	6.18	0.20	-0.15	0.11	0.19
84	262	371	75.03	1.56	9.1	5.82	-1.17	-0.71	-0.78	-0.07
85	237	351	70.98	1.63	9.1	5.55	-0.95	-0.92	-0.78	0.02
86	234	357	71.20	1.76	8.5	4.81	-2.04	-1.87	-1.91	0.19
87	243	389	74.90	2.09	12.9	6.20	0.78	1.03	0.88	0.18
88	238	370	72.75	1.89	12.3	6.50	1.12	1.05	1.11	0.04
89	221	354	69.85	1.89	10.5	5.55	-0.31	-0.59	-0.97	0.18
90	315	447	86.19	1.89	13.2	6.97	0.33	0.58	0.63	-0.07
91	216	310	65.33	1.34	7.4	5.53	-0.81	-0.64	-0.47	-0.13
93	246	376	74.06	1.86	11.6	6.22	0.35	0.07	0.15	0.06
94	272	371	75.85	1.41	10.5	7.41	0.67	0.35	0.38	-0.32
95	270	394	77.77	1.78	11.5	6.47	0.13	-0.06	0.19	-0.03
100	218	361	70.12	2.04	12.1	5.92	0.70	0.66	0.31	0.22
103	261	388	76.48	1.80	10.8	6.01	-0.47	-0.63	-0.78	0.05
105	242	364	72.63	1.74	9.8	5.60	-0.84	-1.14	-0.93	0.08
107	262	386	76.36	1.77	12.5	7.02	1.27	1.45	1.60	-0.10
118	229	367	71.67	1.97	13.4	6.77	2.02	1.83	2.05	0.05
121	215	336	67.59	1.73	9.6	5.54	-0.35	-0.40	-0.31	0.09
123	258	374	74.97	1.66	10.6	6.40	0.02	-0.27	-0.05	-0.08
124	235	377	73.14	2.02	10.2	5.06	-1.46	-0.95	-0.80	0.32
125	217	331	67.36	1.64	9.4	5.71	-0.23	-0.31	-0.17	0.02
126	236	369	72.56	1.90	9.9	5.21	-1.28	-1.24	-1.21	0.22
129	257	358	73.47	1.44	10.8	7.54	1.23	1.05	0.70	-0.31
130	211	346	68.18	1.93	10.3	5.34	-0.45	-0.42	-0.41	0.24
131	247	342	71.16	1.36	9.6	7.06	0.57	0.65	0.77	-0.29

Table A3. Body composition data for experiment 1

ID	Initial REA, cm^2	Final REA, cm^2	Initial 12^{th} rib fat, mm	Final 12^{th} rib fat, mm	Initial rump fat, mm	Final rump fat, mm	Initial IM fat, %	Final IM fat, %	Initial BCS, 1-5	Final BCS, 1-5
20	47.1	75.6	3.81	4.83	2.54	4.57	2.60	2.37	5.50	6.00
21	47.7	59.6	4.06	5.59	3.81	5.33	3.07	2.93	5.00	5.25
22	44.9	70.3	3.56	5.59	3.81	5.84	2.41	2.41	5.50	5.75
24	38.1	54.3	2.29	5.08	3.30	5.33	2.38	2.40	5.50	5.50
25	45.0	62.0	4.06	5.08	4.06	5.59	2.49	2.68	6.00	5.25
27	44.0	62.3	3.56	6.10	3.05	5.84	2.49	2.36	6.00	5.50
28	54.1	86.7	3.81	5.08	3.81	5.33	2.41	3.25	6.00	6.00
29	44.2	74.8	4.06	4.57	3.81	5.08	2.77	3.31	6.00	5.00
30	45.2	75.1	3.56	6.60	3.81	6.86	2.42	2.90	6.00	4.50
34	43.4	53.2	4.06	5.08	4.57	6.10	2.96	2.39	5.50	5.50
35	42.7	54.0	3.56	6.35	3.81	5.59	2.60	2.87	6.00	5.50
39	37.9	49.3	2.79	5.59	2.29	4.57	3.43	2.94	5.00	5.50
41	49.9	72.9	3.56	6.35	4.06	7.37	3.12	3.32	6.50	5.00
42	41.0	61.2	3.56	5.33	3.81	5.08	2.56	2.36	6.00	4.75
44	48.9	70.6	4.32	6.35	3.81	5.33	2.78	2.85	5.50	5.50
45	40.3	58.3	2.29	6.10	2.29	5.59	2.26	2.81	5.50	5.00
46	47.4	69.2	4.06	6.86	4.57	7.62	2.56	2.61	6.00	5.25
47	44.5	56.8	4.06	5.33	3.30	5.33	2.71	3.08	5.50	5.50
48	48.8	73.0	3.81	5.59	3.05	5.33	2.36	2.36	6.00	6.00
49	40.5	65.2	2.79	5.59	3.30	5.08	2.35	2.36	5.50	5.00
51	42.8	65.6	3.56	6.10	2.54	5.33	2.73	2.61	5.00	5.75
52	40.8	72.3	2.54	6.10	2.29	5.84	2.71	2.61	5.00	4.75
57	36.3	60.0	3.81	6.35	3.56	6.10	2.61	2.43	6.00	5.00
58	38.7	54.9	3.56	5.59	3.30	4.83	2.81	2.48	5.50	5.50
60	39.1	55.5	3.81	4.83	2.79	4.57	2.46	2.42	5.00	5.00
63	49.9	71.4	3.56	6.10	3.30	4.57	3.02	2.59	6.00	5.50
65	36.5	64.1	2.79	6.60	3.30	6.86	2.49	2.94	5.50	5.00
69	31.5	47.3	3.05	5.33	3.05	5.33	3.39	2.39	5.00	5.50
70	41.9	63.9	3.56	5.08	3.56	5.33	2.39	2.61	6.00	5.75
71	50.0	61.6	2.79	6.60	4.06	6.86	2.64	2.35	6.00	5.50
73	45.0	67.6	2.79	6.35	2.54	5.33	2.38	2.81	5.50	5.00

Table A3. (continued)

ID	Initial REA, cm^2	Final REA, cm^2	Initial 12^{th} rib fat, mm	Final 12^{th} rib fat, mm	Initial rump fat, mm	Final rump fat, mm	Initial IM fat, %	Final IM fat, %	Initial BCS, 1-5	Final BCS, 1-5
74	39.4	56.3	3.30	3.81	3.05	3.81	3.59	2.91	5.00	4.75
76	35.5	50.5	3.56	4.06	3.05	5.08	3.20	2.97	5.00	5.50
78	45.6	53.0	2.54	5.59	3.30	5.33	2.36	2.59	5.50	5.50
79	46.1	71.2	4.06	5.59	4.57	5.84	2.40	2.40	5.50	5.25
81	41.4	56.1	3.56	4.83	3.05	4.57	2.70	2.48	5.00	5.50
82	44.3	56.9	2.29	6.86	4.57	6.86	2.47	3.54	6.00	5.50
83	38.8	63.0	2.29	5.84	3.81	5.33	2.56	2.37	5.50	4.75
84	44.6	51.7	3.81	4.57	3.05	4.83	2.85	2.72	6.50	5.75
85	40.8	57.2	3.30	5.59	3.05	5.08	2.44	2.46	5.00	5.00
86	42.5	63.5	3.30	5.33	3.05	6.10	2.53	2.68	5.00	5.00
87	35.2	58.6	3.30	5.33	3.05	4.83	2.59	2.83	5.50	4.75
88	36.4	63.7	3.05	5.84	3.05	4.57	3.19	2.57	5.00	4.75
89	31.9	56.4	2.54	6.10	3.30	6.10	2.62	3.13	5.50	4.75
90	54.0	73.5	3.56	4.83	4.57	5.08	2.62	2.63	6.00	5.50
91	35.5	47.8	2.79	4.57	4.06	5.08	3.07	2.38	5.50	5.00
93	41.4	63.2	3.30	6.60	3.81	6.86	2.87	2.57	6.50	4.75
94	41.5	63.5	2.79	5.59	3.81	5.84	2.47	2.65	6.50	5.50
95	37.0	61.2	3.56	6.35	3.81	5.33	2.43	2.36	6.00	4.50
100	36.0	50.7	3.30	6.35	3.05	6.60	2.53	3.08	5.00	5.00
103	38.5	56.6	2.79	5.59	3.05	5.33	2.72	2.87	5.50	5.00
105	46.5	64.5	2.79	6.10	3.81	5.08	2.52	2.39	5.50	5.00
107	41.2	58.3	3.81	5.59	4.06	5.33	2.48	2.46	5.50	5.75
118	33.7	56.2	2.79	6.10	3.30	5.59	2.70	2.37	5.50	4.75
121	38.8	58.9	3.30	6.10	3.81	6.10	2.54	2.50	5.00	5.00
123	45.2	61.2	2.54	5.59	3.30	5.33	2.39	2.39	5.00	4.75
124	42.4	67.7	3.56	4.83	2.79	4.57	2.92	2.42	5.50	5.75
125	36.1	55.7	2.79	5.59	3.05	5.33	2.63	2.45	5.50	4.75
126	37.4	61.4	2.79	5.33	3.05	5.59	3.45	2.60	5.00	5.50
129	42.5	61.9	3.05	5.59	3.05	5.08	2.41	3.12	6.00	4.50
130	39.2	58.1	2.79	5.59	3.56	5.33	2.57	2.61	5.50	5.25
131	40.6	49.4	2.54	4.32	3.05	4.57	2.52	2.48	5.00	5.75

Table A4. Hip height and temperament data for experiment 1

ID	Initial hip height, cm	Final hip height, cm	Initial pen score, 1-5	Initial chute score, 1-5	Final chute score, 1-5	12/17/03 exit velocity, m/s	Initial exit velocity, m/s	Final exit velocity, m/s
20	123	130	2	1.5	1.0	2.58	2.16	1.88
21	126	132	3	1.0	1.0	2.12	3.01	2.56
22	119	126	2	1.0	1.0	1.81	2.53	1.73
24	116	121	3	2.0	1.0	2.21	2.81	2.47
25	114	121	3	1.0	2.0	2.38	3.22	2.98
27	116	126	3	1.0	1.0	1.93	2.20	2.09
28	119	123	2	1.0	1.0	2.19	2.04	2.03
29	123	128	3	1.0	1.0	3.33	2.69	2.12
30	126	131	2	1.0	1.0	1.67	1.86	1.35
34	117	123	2	1.0	1.0	2.47	3.55	1.86
35	117	122	3	1.0	1.0	3.72	2.36	1.61
39	110	117	4	1.0	2.0	2.38	3.24	3.10
41	117	126	2	1.0	2.0	1.58	2.55	1.60
42	123	130	2	1.0	1.0	1.93	2.23	1.59
44	119	126	2	1.0	1.0	2.30	2.75	1.76
45	118	124	4	1.0	2.0	2.74	2.74	3.30
46	119	126	2	1.0	1.0	2.51	2.82	2.58
47	117	123	3	1.0	1.0	2.88	3.67	2.06
48	118	123	2	1.0	1.0	1.94	2.83	2.61
49	121	124	3	1.0	2.0	2.70	3.94	3.23
51	121	131	2	1.0	2.0	1.77	2.24	1.25
52	117	123	2	1.0	1.0	1.65	2.03	1.84
57	116	122	2	1.0	1.0	2.03	2.80	1.83
58	114	121	3	1.0	1.0	3.29	3.36	2.67
60	116	119	4	1.0	2.0	2.46	3.21	2.71
63	116	121	2	1.0	1.0	2.52	3.13	2.53
65	116	122	3	2.0	1.0	3.00	3.36	1.69
69	117	127	3	1.0	1.0	2.60	3.22	3.10
70	112	118	3	1.0	1.0	2.18	3.20	1.94
71	118	126	2	1.0	1.0	2.06	2.85	1.08
73	117	126	2	1.0	1.0	1.46	2.67	1.74

Table A4. (continued)

ID	Initial hip height, cm	Final hip height, cm	Initial pen score, 1-5	Initial chute score, 1-5	Final chute score, 1-5	12/17/03 exit velocity, m/s	Initial exit velocity, m/s	Final exit velocity, m/s
74	118	126	2	1.0	1.0	2.22	1.42	2.28
76	121	126	3	1.0	1.0	3.25	3.18	2.53
78	119	126	2	1.0	1.0	2.68	2.79	2.50
79	126	131	2	1.0	1.0	2.26	2.12	1.67
81	116	122	4	1.0	1.0	1.97	3.59	2.92
82	118	124	3	2.0	1.0	1.95	2.24	2.37
83	119	128	2	1.0	1.0	2.51	2.57	1.61
84	117	123	2	2.0	1.0	2.23	3.46	2.27
85	117	122	2	1.0	1.0	2.11	2.17	2.66
86	114	122	2	1.5	1.0	1.72	2.05	2.29
87	118	126	2	2.0	1.0	2.43	3.36	2.91
88	116	122	3	1.0	1.0	1.85	2.75	2.67
89	116	124	2	1.0	1.0	2.43	2.01	1.52
90	121	127	2	2.0	1.0	2.27	1.86	1.96
91	112	119	2	1.0	1.0	1.93	3.29	2.06
93	117	123	2	1.0	1.0	1.93	1.74	1.46
94	114	121	2	1.0	2.0	2.10	2.58	1.68
95	122	127	2	1.0	1.0	2.31	2.23	1.48
100	110	119	2	1.0	1.0	2.90	2.42	1.43
103	121	127	3	1.0	2.0	2.93	3.31	2.62
105	118	126	4	2.0	1.0	2.29	3.33	2.41
107	114	121	3	1.0	1.0	2.21	2.79	2.25
118	113	123	3	1.0	1.0	2.25	2.20	3.37
121	113	119	2	1.5	2.0	2.34	2.82	2.35
123	121	126	2	1.0	1.0	3.33	2.33	1.20
124	117	126	2	1.0	1.0	1.86	3.14	1.29
125	116	121	4	2.0	2.0	2.57	3.18	2.28
126	112	118	2	1.0	1.0	2.10	3.45	2.86
129	116	123	4	1.0	1.0	2.71	3.81	2.99
130	116	122	3	1.0	1.0	3.03	2.56	1.19
131	117	122	3	2.0	1.0	2.32	2.28	1.19

Table A5. Breeding soundness data for experiment 1

ID	Initial scrotal circum., cm	Final scrotal circum., cm	61-d post trial SC, cm	Penile extens, 5-d post	Semen consist, 5-d post	Motility 5-d post, %	Motility 61-d post, %	Abnormality, 61-d post	Breeding classification
20	24.7	29.6	33.0	YES	THIN	0	60	< 30%	SAT
21	27.6	36.0	34.0	YES	MOD	5	60	< 30%	SAT
22	23.9	30.8	33.0	YES	MOD	10	70	< 30%	SAT
24	24.3	30.3	31.0	YES	MILK	40	80	< 30%	SAT
25	25.2	30.4	31.0	PART	MOD	40	60	< 30%	SAT
27	26.8	32.8	31.0	YES	MOD	50	80	< 30%	SAT
28	26.6	32.9	35.0	PART	THIN	.	80	< 30%	SAT
29	25.8	30.8	33.0	YES	MOD	20	70	< 30%	SAT
30	28.3	36.0	36.0	NO	MOD	20	65	< 30%	SAT
34	22.6	31.7	32.0	YES	MOD	40	80	< 30%	SAT
35	26.8	32.7	33.0	YES	MOD	30	60	< 30%	SAT
39	23.8	31.6	33.0	NO	MOD	30	80	< 30%	SAT
41	24.3	30.7	32.0	YES	THIN	10	20	> 30%	QUES
42	25.8	33.7	36.0	NO	THIN	0	60	< 30%	SAT
44	26.5	31.2	32.0	YES	THIN	20	80	< 30%	SAT
45	28.2	33.6	34.0	YES	MOD	20	70	< 30%	SAT
46	29.0	34.8	37.0	NO	.	.	70	< 30%	SAT
47	26.0	31.5	33.0	NO	MOD	30	65	< 30%	SAT
48	25.8	32.1	34.0	NO	MOD	30	60	< 30%	SAT
49	27.3	32.1	33.0	YES	MILK	50	65	< 30%	UNSAT
51	26.8	33.4	36.0	YES	MOD	10	80	< 30%	SAT
52	21.8	30.9	31.0	PART	MOD	10	70	< 30%	SAT
57	24.4	30.7	32.0	YES	MOD	10	60	< 30%	SAT
58	21.2	27.6	30.0	YES	THIN	.	.	.	UNSAT
60	23.3	31.3	33.0	YES	MOD	20	70	< 30%	SAT
63	27.1	33.6	34.0	YES	MOD	30	80	< 30%	SAT
65	23.8	30.4	31.0	NO	MOD	20	70	< 30%	SAT
69	19.2	28.4	30.0	NO	THIN	10	65	< 30%	SAT
70	23.7	29.0	31.0	YES	MOD	20	80	< 30%	SAT
71	29.0	34.5	36.0	YES	MOD	70	80	< 30%	SAT
73	22.1	28.2	31.0	YES	THIN	.	.	.	UNSAT

Table A5. (continued)

ID	Initial scrotal circum., cm	Final scrotal circum., cm	61-d post trial SC, cm	Penile extens, 5-d post	Semen consist, 5-d post	Motility 5-d post, %	Motility 61-d post, %	Abnor mality, 61-d post	Breed-ing classific ation
74	26.6	32.6	34.0	YES	MOD	50	80	< 30%	SAT
76	23.6	28.3	32.0	YES	THIN	20	70	< 30%	SAT
78	23.9	28.4	26.0	NO	MOD	20	.	.	QUES
79	25.3	33.1	36.0	NO	THIN	10	70	< 30%	SAT
81	25.2	30.2	31.0	PART	MOD	40	40	< 30%	SAT
82	22.9	31.7	32.0	NO	.	.	65	< 30%	SAT
83	25.5	32.6	33.0	YES	MOD	40	65	< 30%	SAT
84	24.8	31.2	32.0	NO	MOD	60	50	< 30%	SAT
85	24.1	30.8	32.0	YES	MOD	10	80	< 30%	SAT
86	26.7	32.6	34.0	YES	MOD	50	80	< 30%	SAT
87	24.3	32.1	35.0	NO	THIN	.	80	< 30%	SAT
88	21.4	27.7	32.0	YES	MOD	20	70	< 30%	SAT
89	21.2	27.9	30.0	PART	MOD	40	70	< 30%	SAT
90	23.0	33.0	36.0	NO	MOD	30	70	< 30%	SAT
91	19.1	26.1	30.0	NO	THIN	10	.	.	UNSAT
93	21.4	30.0	32.0	PART	THIN	10	70	< 30%	SAT
94	26.1	30.1	33.0	NO	MOD	10	60	< 30%	SAT
95	26.5	32.5	35.0	YES	THIN	30	40	< 30%	SAT
100	21.6	27.9	30.0	NO	THIN	0	50	> 30%	QUES
103	23.4	30.3	36.0	YES	THIN	20	60	< 30%	SAT
105	29.3	35.2	34.0	YES	MOD	70	70	< 30%	SAT
107	26.7	32.4	34.0	NO	MOD	30	60	< 30%	SAT
118	22.8	30.3	26.0	NO	THIN	5	60	< 30%	SAT
121	21.2	28.8	33.0	PART	MOD	30	70	< 30%	SAT
123	25.1	30.5	33.0	PART	THIN	5	.	.	UNSAT
124	20.8	26.5	30.0	YES	THIN	.	60	> 30%	QUES
125	25.5	32.8	31.0	YES	MOD	60	80	< 30%	SAT
126	21.0	29.4	33.0	PART	MOD	10	70	< 30%	SAT
129	25.5	30.1	33.0	YES	MOD	10	40	< 30%	SAT
130	19.0	26.4	31.0	NO	MOD	10	65	< 30%	SAT
131	22.9	28.9	32.0	PART	THIN	20	50	< 30%	SAT

APPENDIX B

Table B1. Stocker ADG, and initial feedlot BW data for experiment 2

ID	YR	Sex	Stocker treat-ment	Initial Stocker BW, kg	Stocker ADG, kg/d	Feedlot initation age, d	Feedlot initial BW, kg	Post-adaptation BW,kg
210285	85	ST	NS	318	0.41	390	314	342
210485	85	HF	NS	270	0.51	399	295	323
210585	85	ST	NS	261	0.33	365	294	348
210685	85	HF	LP	289	0.45	387	321	367
210785	85	HF	NS	232	0.59	393	241	280
210885	85	HF	NS	273	0.33	396	302	338
210985	85	ST	NS	293	0.63	383	291	340
211085	85	ST	NS	314	0.53	393	318	379
211185	85	HF	NS	295	0.25	383	289	344
211285	85	HF	LP	273	0.69	376	334	371
211385	85	ST	HP	295	0.67	397	341	377
211585	85	ST	HP	255	0.80	393	320	367
211685	85	ST	HP	266	0.76	393	287	332
211885	85	ST	HP	325	0.57	394	381	439
211985	85	ST	NS	334	0.41	397	330	375
212085	85	ST	LP	280	0.80	388	353	396
212185	85	HF	HP	248	0.72	351	303	333
212385	85	ST	NS	348	0.43	394	354	409
212585	85	ST	NS	320	0.45	401	336	383
212685	85	HF	HP	248	0.69	392	322	367
212785	85	ST	LP	336	0.33	395	373	423
212885	85	HF	LP	266	0.74	401	315	342
213585	85	HF	LP	255	0.59	387	308	340
213785	85	HF	HP	257	0.71	393	315	356
213885	85	ST	HP	255	0.86	366	280	296
214085	85	HF	HP	320	0.76	402	388	423
214285	85	HF	HP	298	0.65	395	332	371
214585	85	ST	NS	320	0.35	366	304	357
214685	85	HF	LP	282	0.67	400	303	340
214785	85	HF	HP	266	0.63	390	290	335
214885	85	ST	HP	270	0.90	377	342	386
215285	85	ST	HP	330	0.80	398	408	453
215485	85	HF	NS	257	0.49	361	273	320
215685	85	ST	NS	286	0.51	397	323	367
215985	85	ST	HP	261	0.76	369	281	313
216085	85	ST	HP	280	0.80	394	279	295
216185	85	HF	NS	259	0.63	393	292	327
216385	85	HF	HP	270	0.61	396	323	361

Table B1. (continued)

ID	YR	Sex	Stocker treat-ment	Initial Stocker BW, kg	Stocker ADG, kg/d	Feedlot initation age, d	Feedlot initial BW, kg	Post-adaptation BW,kg
216985	85	ST	NS	255	0.55	367	283	327
217085	85	HF	HP	239	0.84	379	308	352
217385	85	HF	NS	311	0.27	402	352	395
217485	85	ST	NS	320	0.51	390	311	355
217585	85	HF	HP	218	0.76	379	261	305
217685	85	ST	NS	316	0.39	380	336	382
217885	85	HF	NS	282	0.39	376	265	303
217985	85	HF	LP	252	0.61	387	295	336
218785	85	ST	HP	257	1.04	382	355	407
218885	85	HF	NS	323	0.47	403	354	407
218985	85	ST	HP	268	1.04	401	333	380
219185	85	ST	NS	341	0.59	396	343	400
219285	85	HF	NS	261	0.49	400	269	286
219685	85	HF	NS	275	0.65	379	276	318
219885	85	HF	NS	320	0.53	396	363	400
219985	85	HF	HP	261	0.86	389	325	352
220085	85	HF	HP	225	0.84	382	279	303
220185	85	ST	LP	305	0.72	394	372	419
220285	85	ST	NS	270	0.41	358	288	340
220485	85	HF	NS	298	0.51	393	334	381
220685	85	ST	HP	300	0.57	383	333	377
220785	85	HF	HP	236	0.86	397	287	321
220885	85	HF	NS	245	0.78	397	292	334
221085	85	HF	NS	255	0.57	397	285	321
221585	85	ST	NS	298	0.37	373	314	367
221685	85	ST	LP	314	0.59	383	364	412
221785	85	ST	LP	318	0.82	365	366	410
221885	85	ST	LP	266	0.45	386	264	303
221985	85	ST	NS	300	0.55	400	304	355
222085	85	ST	NS	316	0.47	375	306	354
222585	85	ST	NS	264	0.24	361	270	306
223185	85	HF	NS	295	0.53	390	329	385
210186	86	HF	NS	286	0.33	478	302	341
210286	86	HF	HP	293	0.48	426	313	348
210386	86	HF	LP	307	0.31	436	308	356
210686	86	HF	HP	295	0.60	430	319	365
210886	86	HF	HP	259	0.52	406	268	298
210986	86	ST	HP	286	0.71	440	327	355

Table B1. (continued)

ID	YR	Sex	Stocker treat-ment	Initial Stocker BW, kg	Stocker ADG, kg/d	Feedlot initation age, d	Feedlot initial BW, kg	Post-adaptation BW,kg
211086	86	HF	HP	239	1.04	436	304	323
211186	86	ST	LP	293	0.54	430	332	387
211386	86	ST	HP	316	0.63	437	339	361
211686	86	HF	LP	273	0.61	433	282	317
211786	86	ST	HP	343	0.61	428	368	390
211886	86	HF	LP	293	0.45	478	330	364
212386	86	HF	HP	286	0.58	406	321	355
212586	86	HF	NS	307	0.29	422	310	359
212686	86	ST	HP	264	0.79	421	312	335
213186	86	ST	NS	320	0.24	415	321	360
213286	86	ST	NS	355	0.26	422	361	416
213786	86	HF	HP	302	0.69	435	334	374
213886	86	HF	HP	266	0.55	436	263	297
214386	86	HF	LP	245	0.66	396	265	289
214486	86	HF	HP	293	0.81	404	291	329
214586	86	HF	HP	291	0.49	416	302	316
214686	86	HF	NS	357	-0.08	419	342	414
214786	86	HF	NS	268	0.43	415	273	300
214986	86	HF	HP	305	0.48	427	319	340
215186	86	HF	HP	300	0.50	469	330	361
215486	86	ST	HP	284	0.82	404	338	376
215986	86	ST	LP	284	0.68	415	312	342
216086	86	ST	HP	300	0.65	430	345	366
216186	86	ST	NS	284	0.49	420	293	325
216786	86	ST	HP	325	0.63	419	335	370
216986	86	ST	LP	264	0.53	420	273	302
217086	86	HF	NS	245	0.39	430	249	274
217486	86	HF	HP	293	0.61	423	318	361
217586	86	HF	NS	255	0.56	430	282	311
217686	86	HF	HP	307	0.59	422	325	372
217886	86	ST	HP	307	0.43	417	281	277
218786	86	ST	HP	327	0.63	409	351	399
218886	86	ST	LP	255	0.55	423	298	351
219386	86	HF	NS	336	0.35	430	324	339
219686	86	ST	HP	248	0.93	416	311	367
219886	86	HF	NS	282	0.30	435	270	300
219986	86	ST	LP	339	0.32	437	344	375
220286	86	ST	HP	334	0.66	423	375	403

Table B1. (continued)

ID	YR	Sex	Stocker treat-ment	Initial Stocker BW, kg	Stocker ADG, kg/d	Feedlot initation age, d	Feedlot initial BW, kg	Post-adapt BW,kg
220586	86	HF	HP	250	0.64	423	289	322
220686	86	ST	NS	341	0.54	429	365	412
220886	86	HF	HP	250	0.76	421	294	327
221086	86	ST	HP	293	0.83	408	353	404
221486	86	ST	LP	309	0.14	430	285	313
221586	86	HF	HP	277	0.60	434	304	348
221686	86	HF	LP	289	0.41	419	322	362
221786	86	ST	NS	389	0.17	430	381	447
221886	86	ST	HP	318	0.54	418	364	425
222086	86	HF	HP	257	0.62	399	272	303
222286	86	ST	HP	270	0.83	428	321	351
222486	86	HF	NS	284	0.38	423	296	342
223386	86	ST	NS	275	0.41	386	286	328
420686	86	HF	HP	255	0.60	428	290	310
421486	86	HF	HP	248	0.62	429	250	271
421586	86	HF	HP	234	0.60	422	254	285
422386	86	ST	HP	239	1.05	420	312	325
423186	86	ST	HP	245	0.83	406	315	357

Table B2. Performance data for experiment 2

ID	Model ADG, kg/d	Post-adapt ADG, kg/d	DMI, kg/d	Post-adapt DMI	RFI, kg/d	Post-adapt RFI, kg/d	FCR	Post-adapt FCR	RG, kg/d	Post-adapt RG, kg/d
210285	0.83	0.80	6.82	7.01	0.14	0.39	8.18	8.76	-0.18	-0.18
210485	0.96	0.95	7.63	7.74	0.52	0.41	7.91	8.11	-0.15	-0.10
210585	1.48	1.29	9.26	9.05	0.46	0.61	6.26	7.02	0.16	0.09
210685	1.41	1.31	8.15	8.97	-0.95	-0.27	5.78	6.84	0.21	0.12
210785	1.10	1.02	6.48	6.72	-0.41	-0.17	5.90	6.61	0.16	0.07
210885	1.00	0.90	7.80	7.53	0.78	0.11	7.82	8.33	-0.14	-0.13
210985	1.43	1.34	10.59	9.52	1.75	0.74	7.42	7.11	-0.07	0.09
211085	1.37	1.15	8.58	9.72	0.21	1.25	6.24	8.45	0.11	-0.12
211185	1.45	1.31	8.04	8.56	-0.43	-0.35	5.53	6.55	0.28	0.16
211285	1.10	1.02	8.55	8.57	0.30	0.24	7.73	8.42	-0.14	-0.13
211385	1.01	0.92	7.31	7.57	-0.04	-0.08	7.27	8.20	-0.09	-0.12
211585	1.30	1.13	8.28	8.05	-0.24	-0.15	6.38	7.15	0.09	0.03
211685	1.27	1.17	7.42	8.20	-0.17	0.35	5.84	6.98	0.18	0.07
211885	1.40	1.11	10.17	9.52	0.54	0.32	7.26	8.61	-0.09	-0.14
211985	1.15	0.95	7.69	7.85	-0.45	0.10	6.70	8.26	0.01	-0.12
212085	1.46	1.44	10.29	9.90	0.79	0.24	7.03	6.86	-0.03	0.15
212185	0.94	0.91	7.40	7.24	0.27	-0.06	7.85	8.00	-0.15	-0.10
212385	1.56	1.40	9.97	10.46	0.13	0.74	6.38	7.47	0.11	0.05
212585	1.60	1.57	9.86	10.12	0.12	0.23	6.16	6.45	0.17	0.26
212685	1.23	1.07	8.72	8.63	0.22	0.19	7.11	8.06	-0.04	-0.08
212785	1.08	0.77	8.89	8.73	0.43	0.85	8.24	11.34	-0.23	-0.39
212885	1.07	1.10	5.96	6.95	-1.48	-1.20	5.57	6.33	0.15	0.12
213585	1.11	1.10	7.19	7.19	-0.32	-0.96	6.46	6.52	0.05	0.10
213785	0.98	0.86	6.89	6.91	-0.55	-0.58	7.00	8.04	-0.05	-0.11
213885	1.02	1.15	6.26	6.61	-0.66	-0.58	6.14	5.75	0.08	0.21
214085	1.10	1.02	9.47	9.32	0.56	0.19	8.62	9.14	-0.30	-0.21
214285	1.35	1.33	7.31	7.89	-1.73	-1.46	5.41	5.95	0.25	0.25
214585	1.48	1.37	8.82	10.17	0.26	1.28	5.95	7.44	0.19	0.05
214685	1.45	1.50	9.41	9.92	0.76	0.38	6.47	6.61	0.09	0.21
214785	1.24	1.13	7.77	8.40	0.06	0.24	6.28	7.45	0.10	0.00
214885	1.60	1.60	9.68	9.40	-0.11	-0.63	6.07	5.87	0.18	0.37
215285	1.35	1.24	9.34	9.66	-0.45	-0.17	6.93	7.81	-0.06	-0.03
215485	1.14	1.00	6.55	6.80	-0.77	-0.86	5.76	6.81	0.16	0.04
215685	1.27	1.13	8.67	8.54	0.22	0.34	6.85	7.59	0.01	-0.02
215985	1.34	1.41	5.62	6.13	-2.15	-2.23	4.19	4.36	0.48	0.52
216085	1.16	1.33	8.22	8.51	1.14	0.68	7.11	6.39	-0.02	0.19
216185	1.02	0.96	8.15	8.16	0.90	0.77	8.03	8.53	-0.16	-0.15
216385	1.22	1.17	7.97	8.40	-0.53	-0.28	6.52	7.17	0.05	0.04

Table B2. (continued)

ID	Model ADG, kg/d	Post-adapt ADG, kg/d	DMI, kg/d	Post-adapt DMI	RFI, kg/d	Post-adapt RFI, kg/d	FCR	Post-adapt FCR	RG, kg/d	Post-adapt RG, kg/d
216985	0.92	0.74	6.52	7.00	0.07	0.60	7.07	9.41	-0.04	-0.24
217085	1.32	1.20	8.99	8.93	0.37	0.27	6.84	7.42	0.02	0.02
217385	1.29	1.18	9.24	9.97	0.14	0.75	7.15	8.46	-0.06	-0.12
217485	1.55	1.56	7.62	8.58	-1.61	-0.84	4.93	5.50	0.41	0.41
217585	1.20	1.10	7.50	8.39	-0.04	0.77	6.24	7.59	0.11	-0.02
217685	1.36	1.22	8.76	8.94	-0.17	0.19	6.44	7.31	0.08	0.04
217885	1.19	1.15	6.57	7.01	-0.65	-0.74	5.52	6.07	0.23	0.17
217985	1.19	1.12	8.54	8.99	0.92	0.87	7.16	8.06	-0.04	-0.08
218785	1.05	0.71	7.72	7.36	-0.42	-0.08	7.36	10.37	-0.10	-0.31
218885	1.40	1.20	9.80	9.85	0.31	0.38	7.01	8.20	-0.03	-0.08
218985	1.40	1.28	10.55	9.34	1.51	0.44	7.53	7.31	-0.10	0.05
219185	1.14	0.79	7.75	8.32	-0.54	0.73	6.80	10.53	-0.01	-0.33
219285	0.84	0.90	5.92	6.10	-0.22	-0.65	7.08	6.80	-0.04	0.01
219685	1.25	1.18	7.10	7.63	-0.46	-0.44	5.69	6.48	0.21	0.13
219885	1.07	0.95	5.97	5.73	-2.52	-2.84	5.60	6.01	0.13	0.11
219985	0.83	0.79	7.44	7.37	0.45	0.19	9.00	9.28	-0.27	-0.23
220085	0.76	0.73	6.05	6.16	-0.08	-0.03	7.96	8.41	-0.13	-0.16
220185	1.35	1.20	9.31	9.44	-0.05	0.22	6.88	7.87	-0.02	-0.04
220285	1.04	0.83	7.92	7.28	0.80	0.57	7.59	8.74	-0.11	-0.18
220485	1.16	0.94	9.63	8.28	1.18	0.04	8.29	8.78	-0.22	-0.17
220685	1.18	1.01	7.95	7.79	-0.33	-0.18	6.74	7.70	0.01	-0.05
220785	0.92	0.84	6.23	6.40	-0.61	-0.50	6.79	7.57	-0.01	-0.07
220885	1.14	1.04	8.14	8.16	0.75	0.34	7.14	7.87	-0.04	-0.07
221085	1.04	0.97	7.12	7.23	-0.13	-0.14	6.87	7.43	-0.01	-0.03
221585	1.71	1.64	10.56	9.89	0.75	0.02	6.19	6.04	0.20	0.35
221685	1.63	1.58	11.51	10.36	1.34	0.01	7.08	6.55	-0.03	0.24
221785	1.34	1.24	8.09	7.92	-1.15	-1.30	6.05	6.38	0.12	0.16
221885	1.40	1.41	9.58	8.17	1.83	-0.06	6.86	5.78	0.05	0.31
221985	1.38	1.26	7.59	8.51	-0.62	0.02	5.49	6.77	0.25	0.12
222085	1.35	1.25	8.67	9.89	0.55	1.44	6.43	7.91	0.08	-0.04
222585	1.02	0.95	6.19	5.57	-0.60	-1.04	6.08	5.89	0.10	0.12
223185	1.60	1.43	9.93	10.22	0.08	0.33	6.19	7.15	0.17	0.11
210186	1.21	1.22	8.81	10.83	0.56	1.01	7.25	8.87	-0.05	-0.17
210286	0.90	0.86	7.52	7.40	0.60	0.51	8.33	8.59	-0.21	-0.16
210386	1.31	1.22	8.36	10.13	-0.30	0.09	6.38	8.31	0.09	-0.09
210686	1.27	1.21	8.60	9.37	-0.04	-0.78	6.79	7.76	0.01	-0.02
210886	1.17	1.21	6.68	6.69	-0.68	-0.78	5.73	5.53	0.17	0.26
210986	0.61	0.53	5.29	4.78	-0.47	-0.53	8.72	8.95	-0.22	-0.21

Table B2. (continued)

ID	Model ADG, kg/d	Post-adapt ADG, kg/d	DMI, kg/d	Post-adapt DMI	RFI, kg/d	Post-adapt RFI, kg/d	FCR	Post-adapt FCR	RG, kg/d	Post-adapt RG, kg/d
211086	0.75	0.78	5.83	5.93	-0.37	-0.26	7.80	7.61	-0.14	-0.09
211186	1.02	0.85	6.89	6.49	-0.54	-0.50	6.75	7.66	-0.04	-0.08
211386	0.86	0.91	6.21	6.25	-0.69	-0.60	7.20	6.86	-0.11	0.01
211686	1.12	1.12	8.08	8.17	0.73	0.74	7.24	7.26	-0.06	0.02
211786	1.12	1.29	10.25	11.12	1.70	0.77	9.18	8.65	-0.37	-0.13
211886	1.01	0.99	8.20	7.95	0.66	0.32	8.15	8.01	-0.21	-0.09
212386	1.50	1.67	9.73	11.55	0.27	0.00	6.51	6.91	0.09	0.21
212586	1.38	1.30	9.05	10.96	0.12	0.61	6.56	8.46	0.07	-0.10
212686	1.11	1.20	8.91	8.50	1.41	0.95	8.06	7.11	-0.20	0.06
213186	1.07	1.03	6.29	5.96	-1.17	-1.32	5.89	5.80	0.09	0.16
213286	1.47	1.36	9.38	10.57	-0.30	-0.43	6.39	7.75	0.08	0.01
213786	1.45	1.54	9.17	11.19	-0.30	-0.21	6.32	7.25	0.10	0.12
213886	0.88	0.84	6.30	6.29	0.12	0.27	7.14	7.49	-0.05	-0.06
214386	1.07	1.14	6.64	6.79	-0.30	-0.28	6.21	5.93	0.08	0.19
214486	1.42	1.55	8.60	11.16	-0.23	0.40	6.04	7.19	0.18	0.13
214586	0.88	0.98	6.88	6.94	0.20	0.08	7.83	7.09	-0.15	0.01
214686	1.78	1.57	11.34	13.46	0.62	1.35	6.36	8.55	0.14	-0.09
214786	1.12	1.19	7.44	7.68	0.19	0.26	6.64	6.44	0.03	0.14
214986	0.99	1.13	8.40	9.86	0.71	0.34	8.49	8.69	-0.23	-0.15
215186	1.00	1.05	7.94	9.61	0.06	0.05	7.91	9.12	-0.16	-0.20
215486	0.90	0.83	7.38	7.16	0.33	0.41	8.18	8.65	-0.21	-0.17
215986	1.09	1.14	7.90	7.97	0.45	0.56	7.22	7.02	-0.08	0.05
216086	0.58	0.55	7.14	6.84	1.27	1.29	12.38	12.33	-0.49	-0.41
216186	1.00	1.00	6.81	6.77	-0.04	0.12	6.80	6.76	-0.02	0.05
216786	1.05	1.04	7.08	6.97	-0.48	-0.51	6.76	6.71	-0.04	0.06
216986	0.67	0.62	6.23	6.17	0.91	1.34	9.25	9.89	-0.24	-0.27
217086	0.82	0.83	6.60	6.59	0.83	0.97	8.03	7.93	-0.13	-0.11
217486	1.24	1.20	8.46	9.97	-0.08	-0.07	6.82	8.33	0.01	-0.10
217586	0.94	0.94	7.83	7.77	1.19	1.14	8.37	8.24	-0.20	-0.12
217686	1.37	1.32	9.17	11.28	0.09	0.65	6.69	8.54	0.04	-0.11
217886	0.78	1.01	5.18	5.49	-0.66	-0.45	6.64	5.43	-0.01	0.19
218786	1.10	1.01	7.33	6.98	-0.65	-0.81	6.64	6.92	-0.03	0.03
218886	1.02	0.85	6.51	6.10	-0.47	-0.37	6.40	7.17	0.03	-0.03
219386	1.13	1.41	9.37	11.59	1.14	1.16	8.30	8.21	-0.22	-0.06
219686	1.73	1.72	10.85	13.13	0.89	1.66	6.27	7.63	0.18	0.09
219886	0.78	0.75	5.75	5.72	-0.15	0.03	7.33	7.67	-0.07	-0.10
219986	0.78	0.73	8.52	7.77	1.86	1.38	10.86	10.58	-0.47	-0.33
220286	0.65	0.56	6.60	7.23	-0.45	-0.88	10.10	12.86	-0.36	-0.44

Table B2. (continued)

ID	Model ADG, kg/d	Post-adapt ADG, kg/d	DMI, kg/d	Post-adapt DMI	RFI, kg/d	Post-adapt RFI, kg/d	FCR	Post-adapt FCR	RG, kg/d	Post-adapt RG, kg/d
220586	1.00	0.99	6.57	6.46	-0.42	-0.52	6.56	6.54	0.01	0.07
220686	1.38	1.33	8.37	9.23	-1.06	-1.58	6.05	6.96	0.12	0.11
220886	1.28	1.39	7.37	8.82	-1.01	-1.37	5.75	6.33	0.20	0.22
221086	1.11	0.89	7.22	7.59	-1.11	-1.62	6.53	8.53	0.01	-0.15
221486	1.14	1.20	6.12	6.13	-1.16	-1.12	5.38	5.09	0.20	0.32
221586	1.27	1.23	8.33	9.83	-0.15	-0.12	6.55	8.02	0.06	-0.06
221686	1.00	0.88	8.56	9.61	0.80	0.62	8.56	10.93	-0.24	-0.38
221786	1.48	1.21	8.80	9.75	-1.16	-1.16	5.94	8.09	0.15	-0.07
221886	1.42	1.20	9.92	11.26	0.39	0.69	7.01	9.39	-0.04	-0.23
222086	1.05	1.07	6.81	6.90	-0.15	-0.09	6.49	6.47	0.04	0.10
222286	0.87	0.85	5.76	5.62	-0.93	-0.84	6.65	6.62	-0.03	0.02
222486	1.53	1.54	9.05	10.90	-0.21	-0.01	5.91	7.09	0.22	0.14
223386	1.35	1.36	7.38	8.46	-0.93	-1.20	5.48	6.22	0.26	0.23
420686	0.81	0.85	6.55	6.39	0.30	0.14	8.11	7.55	-0.16	-0.07
421486	1.06	1.15	5.50	5.80	-1.19	-1.04	5.21	5.02	0.23	0.30
421586	1.12	1.15	6.71	6.79	-0.29	-0.25	5.99	5.90	0.13	0.19
422386	0.74	0.82	5.94	5.99	-0.12	0.06	8.09	7.35	-0.17	-0.06
423186	1.33	1.32	8.26	8.00	-0.12	-0.35	6.23	6.06	0.08	0.23

Table B3. Carcass data for experiment 2

ID	Hot carcass wt, kg/d	REA, cm^2	12^{th} rib fat, cm	KPH, %	Dressing percent	Yield grade	Quality grade
210285	304	85.8	0.25	1.5	64.1	1.34	3.80
210485	309	85.8	1.78	1.5	64.5	2.88	4.00
210585	313	86.5	1.02	1.5	65.4	2.13	5.00
210685	317	83.9	1.52	2.0	62.9	2.89	4.00
210785	297	76.1	0.89	2.5	64.9	2.58	4.00
210885	293	88.4	1.02	1.5	63.3	1.86	3.80
210985	299	75.5	0.25	1.5	57.1	1.81	3.20
211085	339	94.2	0.64	1.0	64.7	1.48	4.80
211185	327	101.9	1.14	2.0	65.2	1.71	4.00
211285	283	89.7	0.76	2.5	60.3	1.67	3.20
211385	318	94.8	0.69	1.0	63.5	1.33	3.20
211585	297	80.7	0.89	2.0	61.5	2.26	4.00
211685	313	88.4	1.02	1.0	64.4	1.93	3.20
211885	343	97.4	0.58	2.0	62.4	1.51	3.20
211985	293	87.7	0.18	1.0	61.7	0.97	1.50
212085	345	83.9	1.27	2.0	62.5	2.87	4.00
212185	312	78.7	0.25	1.5	65.7	1.75	3.20
212385	328	84.5	0.76	2.0	60.3	2.20	3.80
212585	327	87.7	0.51	2.0	61.1	1.78	3.20
212685	298	85.8	0.56	2.0	63.2	1.69	3.80
212785	321	85.2	0.64	1.5	63.5	1.88	3.80
212885	320	91.0	1.02	1.5	64.7	1.96	4.00
213585	316	76.8	1.52	2.0	65.2	3.24	3.80
213785	316	85.2	0.76	2.5	63.9	2.17	3.20
213885	321	84.5	0.94	3.0	66.2	2.52	3.80
214085	336	103.2	1.02	2.0	64.7	1.59	3.80
214285	308	83.2	0.76	2.5	61.2	2.20	4.00
214585	353	88.4	0.51	1.5	68.8	1.87	4.00
214685	337	83.9	0.69	1.5	62.7	2.13	3.80
214785	303	83.2	0.76	1.5	62.8	1.95	3.20
214885	297	100.7	0.25	2.0	53.9	0.64	1.50
215285	370	87.7	0.89	2.0	62.8	2.52	3.80
215485	291	82.6	0.76	1.5	58.4	1.89	3.20
215685	301	93.6	0.43	2.0	62.9	1.20	3.80
215985	308	73.6	.	1.5	61.2	1.73	2.00
216085	284	87.1	0.51	1.5	60.2	1.35	2.00
216185	272	78.1	0.43	2.0	55.5	1.73	3.20
216385	293	91.0	0.64	1.5	62.3	1.36	3.20

Table B3. (continued)

ID	Hot carcass wt, kg/d	REA, cm^2	12^{th} rib fat, cm	KPH, %	Dressing percent	Yield grade	Quality grade
216985	266	70.3	0.51	2.0	62.0	2.14	3.20
217085	306	87.1	0.81	1.5	64.4	1.84	3.80
217385	317	102.6	0.51	2.0	62.3	0.96	4.00
217485	319	87.7	0.18	1.5	61.3	1.29	2.00
217585	310	83.9	0.76	2.0	63.0	2.08	4.00
217685	306	100.7	0.18	1.5	60.6	0.54	2.00
217885	286	78.7	0.43	1.5	62.9	1.72	3.20
217985	302	81.9	1.02	1.0	63.6	2.16	3.20
218785	286	80.7	0.51	1.5	60.7	1.69	3.80
218885	338	74.2	1.52	1.5	64.4	3.44	4.00
218985	315	80.7	0.64	1.5	60.5	2.06	3.80
219185	292	66.5	0.25	1.0	60.6	2.09	3.20
219285	293	71.0	0.51	2.0	67.4	2.33	3.20
219685	293	66.5	0.51	1.5	62.6	2.45	3.80
219885	316	88.4	1.14	1.5	63.4	2.19	4.00
219985	332	81.3	0.51	2.0	67.0	2.14	3.80
220085	272	65.8	0.51	1.5	64.1	2.31	3.20
220185	327	84.5	0.76	1.0	60.7	1.99	4.00
220285	286	67.7	0.38	1.5	61.4	2.21	3.20
220485	299	82.6	0.69	1.5	64.0	1.88	3.80
220685	295	72.3	0.51	1.0	61.5	2.08	3.20
220785	295	80.0	0.76	1.5	64.1	2.05	4.00
220885	303	85.2	0.51	1.5	64.3	1.61	4.00
221085	296	83.9	1.02	2.5	62.8	2.32	3.20
221585	322	80.7	0.38	1.5	59.5	1.87	3.80
221685	345	89.0	0.76	2.0	60.5	2.12	4.00
221785	295	77.4	0.38	1.0	55.5	1.70	3.20
221885	304	76.8	0.76	1.5	61.9	2.28	3.20
221985	331	107.1	0.18	1.5	63.9	0.43	3.80
222085	318	97.4	0.25	1.5	60.9	0.87	3.80
222585	291	78.1	0.30	2.0	61.9	1.76	3.80
223185	348	98.7	1.02	1.5	65.7	1.81	4.00
210186	313	99.4	1.12	1.5	65.6	1.60	3.50
210286	325	80.0	1.22	1.5	64.7	2.70	5.30
210386	319	83.2	1.22	1.5	64.2	2.50	3.80
210686	315	89.0	1.42	1.5	61.5	2.40	3.60
210886	.	.	.	.	.	.	.
210986	224	63.9	0.30	1.0	49.2	1.30	3.60

Table B3. (continued)

ID	Hot carcass wt, kg/d	REA, cm^2	12^{th} rib fat, cm	KPH, %	Dressing percent	Yield grade	Quality grade
211086	256	65.2	1.02	1.5	55.4	2.70	3.30
211186	339	80.7	0.51	1.5	63.0	2.00	3.50
211386	313	82.6	0.20	1.5	59.3	1.40	3.60
211686	332	80.7	1.32	1.5	64.9	2.90	3.40
211786	348	88.4	0.41	1.5	62.8	1.70	3.40
211886	339	72.3	2.03	2.5	61.9	4.30	4.30
212386	335	106.5	0.81	2.0	59.3	1.25	4.40
212586	320	83.9	0.81	2.0	62.3	2.20	3.50
212686	.	.	.	.	.	.	.
213186	357	85.8	1.22	1.5	65.2	2.80	4.40
213286	373	97.4	1.22	1.5	64.4	2.20	3.80
213786	360	111.0	0.71	2.0	64.1	1.10	3.30
213886	225	61.9	.	1.0	51.3	1.50	2.60
214386	300	90.3	0.30	1.5	60.6	1.10	3.40
214486	298	92.9	0.71	1.0	58.5	1.30	3.50
214586	319	77.4	0.71	1.5	65.5	2.30	3.50
214686	387	113.6	1.83	1.5	64.7	2.20	3.60
214786	318	89.7	0.81	1.5	62.1	1.80	4.00
214986	295	99.4	0.41	1.0	61.9	0.70	3.30
215186	319	91.6	1.22	2.0	65.5	2.20	3.70
215486	.	.	.	.	.	.	.
215986	328	75.5	0.81	2.0	61.5	2.60	3.40
216086	288	75.5	0.20	1.5	62.3	1.40	2.80
216186	321	82.6	1.02	1.5	63.9	2.20	3.40
216786	351	78.7	0.71	1.5	63.5	2.40	3.80
216986	275	71.6	.	1.0	66.4	1.50	2.40
217086	288	96.1	0.30	1.5	68.0	1.00	3.40
217486	321	92.3	0.71	1.5	64.3	1.50	3.70
217586	273	87.1	0.71	1.5	55.8	0.00	4.10
217686	323	103.2	0.61	1.5	60.8	0.90	3.70
217886	268	80.0	.	1.0	58.0	1.00	3.00
218786	354	83.2	0.71	1.5	61.3	2.30	4.00
218886	314	78.1	0.51	1.0	63.0	1.90	3.40
219386	313	96.8	0.91	1.0	61.0	1.40	3.20
219686	352	89.7	1.12	1.5	61.9	2.40	3.80
219886	275	82.6	0.20	1.0	64.0	1.90	3.40
219986	.	.	.	.	.	.	.
220286	279	82.6	0.20	1.0	60.7	1.10	2.80

Table B3. (continued)

ID	Hot carcass wt, kg/d	REA, cm^2	12^{th} rib fat, cm	KPH, %	Dressing percent	Yield grade	Quality grade
220586	305	87.7	0.30	1.5	62.1	1.30	3.90
220686	339	88.4	0.61	1.5	59.9	1.85	4.80
220886	309	100.7	0.81	1.0	62.1	1.10	4.60
221086	315	85.8	0.51	1.0	62.4	1.80	3.50
221486	218	63.2	0.20	1.0	41.1	1.40	1.30
221586	295	87.7	1.22	1.0	59.0	2.10	4.70
221686	295	80.7	1.63	1.5	64.2	2.85	3.60
221786	363	92.3	0.51	1.5	62.4	1.75	5.60
221886	359	100.0	1.32	2.0	64.1	2.25	4.40
222086	255	72.3	0.41	1.5	52.0	1.60	3.40
222286	296	70.3	0.20	1.0	58.2	1.90	3.60
222486	321	105.2	0.81	1.0	61.6	1.00	4.80
223386	308	92.9	0.41	1.0	62.8	1.10	3.70
420686	299	87.1	0.61	1.5	65.3	1.60	3.30
421486	.	.	.	.	.	.	.
421586	303	86.5	0.61	1.0	60.9	1.40	3.50
422386	291	74.8	0.41	1.5	61.1	1.80	3.40
423186	381	76.1	1.42	2.0	63.5	3.40	5.00

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